The Manufacture, Distribution and Use of Gas in Philadelphia

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View of a Portion of the Philadelphia Gas Works at Passyunk Avenue and Schuylkill River

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The Beginning of the Use of Illuminating Gas

ABOUT the year 1792 an English engineer put a piece of soft coal in the bowl of a clay pipe. He filled the bowl of the pipe on top of the coal with a plug of clay so that no air could get to the coal. He then put the bowl of the pipe upside down in a fire, leaving the stem sticking out. When the bowl of the pipe was red hot he found that gas was pouring from the stem and that when lighted it gave a rich, luminous flame. When the gas had ceased pouring from the stem he took the bowl out of the fire, removed the clay and found that his lump of coal had changed its shape and had been converted into a piece of coke, which he found to consist of pure carbon and some ash.

The lump of coal had been made hot enough to burn if oxygen had been present with it, but all air had been kept away by the plug of clay. Instead of burning, the coal had become red hot and had first melted to a plastic and sticky mass from which came off bubbles of what seemed to be a dense, smoky gas. The melted coal then hardened to red, porous coke which still gave off gas in diminishing quantity until there was left nothing but a lump of hot coke, which, after removal and cooling, became a gray coke with a shining luster.

OTHER PRODUCTS FROM COAL:

This gas coming from the coal, if allowed to flow out unlighted, still hot from the end of the stem of the pipe, would have been found to be black and smoky with a strong odor of tar. It would not be in the same condition as the pure, colorless gas which the consumer finds coming from his burner, but would contain in addition to that gas a number of other materials such as tar, steam, ammonia, cyanogen, lamp-black, benzols, and vapors of other oils consisting of carbon and hydrogen in chemical combination with each other, gases of sulphur and carbon, other gases of sulphur and hydrogen and carbon and oxygen.

To the gas manufacturer these additional substances are known as by-products of coal-gas manufacture. The gas must be cleaned, then, before it leaves the gas works. If this is not done some of these by-products would condense in the mains, form stoppages and reduce the rate of flow of gas. Other vapors and mists would carry longer distances and there condense, and again here and there in the smaller pipes and in the burners the stoppages would shut off the flow of gas; and even when the gas arrived at the consumer's house and was burnt, the air would be contaminated with burnt impurities that would cause serious inconvenience and discomfort in breathing and would be disagreeable in other ways.

SEPARATING THE GAS FROM THE BY-PRODUCTS:

The removal of all of these impurities is accomplished in the gas works by a system of carefully cooling the gas in condensers or coolers, then washing the gas in contact with cold water, and finally by forcing the gas through purifiers to remove that portion which when burnt would cause distress to the people present.

While we are now dealing only with illuminating gas, it is well to say here that these other products, from which the illuminating gas must be freed before it can be used, form a most interesting and valuable group of materials for the use of man. From them are made, by chemical processes (some of which are long and difficult, requiring knowledge and skill possessed by few), a great number of aniline dyes, many drugs and medicines, explosives, perfumes, disinfectants, germicides and creosotes, materials for ice making, road making, roofing and a great list of other materials used in the trades, arts and sciences.

The production from black tar of pure white saccharin, a substance having a sweetening effect five hundred times that of the same weight of sugar, is a single illustration of the many unexpected uses that have been found for these materials.

FIRST USE OF THE WORD GAS:

Long before the period when illuminating gas was first exhibited, about 1797, it was known that there existed and could be produced gases differing very greatly in their properties from the mixture of nitrogen and oxygen that forms our atmosphere. About the year 1600 Van Helmont in his writings shows that he was aware of these other gaseous materials and he called them "spirit," using the German word "geist" (meaning spirit), and from this the word "gaz" (French), or "gas" (English) came into use. His idea appears to have been that this spirit or "geist" could be reduced into solid form, and that many solid bodies were made up almost entirely of this spirit. Later, other experimenters learned more and more about the different gases until our forefathers of one hundred years ago, under the leadership of William Murdock, first realized that the material coming off the coal contained good illuminating gas, from which the heavy by-products could be separated, leaving the gas itself to be passed through miles of pipe without losing in value. They did not at once realize the full force of what this conversion of coal into gas meant to mankind. It took them almost twenty years to put in force this new idea.

FORMATION OF THE GAS COMPANY:

That idea was: Instead of each householder going out to replenish his supply of candles or oil for lighting, of wood or coal for heating and cooking, why not bring the coal or wood (for wood when plentiful was formerly used for gas making) into some place in or near the city, there convert it into gas and force the gas through pipes laid in the streets and houses, so that when light or heat was wanted it was only necessary to turn a valve and apply a lighted match?

To do this required the building of a gas plant and for this a company was formed and stock sold to provide money for installing the entire plant. This required the use of the city streets for laying the distribution mains. If a gas works had been provided within each of the city blocks it would not have been necessary to cross the city streets with mains, but as this, of course, was impossible for many reasons the use of the streets became absolutely necessary and, since the streets are owned by the city, the consent of the city authorities had to be obtained for laying the pipes in them for distributing the gas. This permission is called a "franchise" and no company or person not possessing such a franchise may open the streets to lay

pipe for any purpose. Those companies to whom such franchises are given and who use the streets below, on or above the surface, are in turn required to sell their products to any and all of the general public who comply with necessary rules, and such companies are known as public service companies or corporations.

Accustomed as we are to its benefits, it is not easy for us to realize what a change came into the lives of human beings through this century-old idea of introducing gas for household uses,—or what it meant in saving of labor and of time, in equalizing temperatures so that the cold, cheerless room became cozy again, and the stifling kitchen became a pleasant place to work in; of the elimination of dust, dirt, odors, and lamp dangers; of its immense meaning to the race in its invitation to improved cookery!

And when we consider the great advances in the industries, sciences and arts due to new discoveries and uses of other residuals from the distillation of coal, we may truthfully say that the Nineteenth Century, excelling as it did all previous periods in adaptation of newly discovered laws of physics and chemistry to the benefit of mankind, contains no more important event than the development due to the distillation of bituminous or soft coal for gas making and the use of the by-products in the arts and sciences.

RELATION OF THE GAS COMPANY TO THE CITY:

The city, representing all the people, gives to the gas company the use of the streets for distributing mains, protects the company against competition and thereby becomes an interested party in the gas business.

How, then, can the city be sure that the gas company will do its duty in giving a good quality of gas at a fair price and a good supply to all the houses? And how can the gas company be sure that laws will not be passed hastily and through ignorance of the business, that will put unnecessarily heavy burdens on the gas company?

In the last 100 years of dealings between the gas companies and the public many methods of solving these problems have been tried, some of which have been found good and others complete failures. At the present time in many states, including Pennsylvania, all such questions are referred to a body of men appointed by the Governor and known as the Public Service Commission. These men, giving all their time to the questions of rates and the business of public service corporations and being acquainted with all the laws and the principles involved in conducting the business, stand as a court of appeal before which the corporations, the consumers and the general public may lay their grievances.

COMPOSITION OF COAL GAS:

Illuminating gas made from soft coal is a mixture of a number of simpler gases and a minute percentage of vapors. Some of these gases in burning give heat and no light, such as hydrogen and carbon monoxide; others give great heat and little light, such as methane; others give both great heat and great light, such as naphthaline; others give a comparatively small amount of heat but are of great illuminating value, such as benzine; still others give neither light nor heat, such as carbon dioxide, oxygen and nitrogen. These last are unavoidably present in very small percentages of the whole.

Principles Involved in the Manufacture, Distribution and Sale of Illuminating Gas

COAL GAS MANUFACTURE:

In the gas works the bowl of the pipe becomes a retort and Figures 1 and 2 show a simple retort and method of heating:

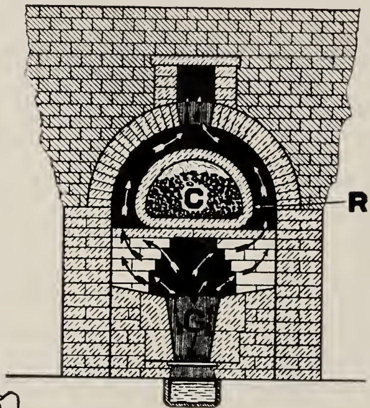


FIG. 1

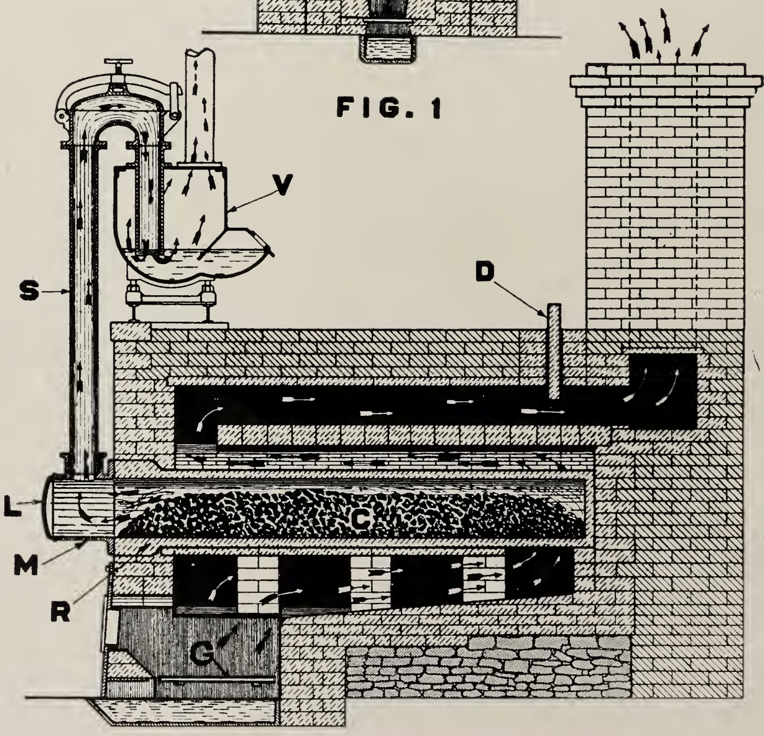


FIG. 2

Simple Form of Coal Gas Retort

The lid "L" is taken off the cast iron mouthpiece "M," which is fastened to the retort "R." The coal "C" is then charged into the retort by shovels or machinery. The retort "R," having one opening at the front end, is made of fire clay so that it can be kept for several years at a bright orange heat without melting, bending or breaking. After the retort is charged, the lid "L" is replaced on the mouthpiece "M" and then there is no way for the gas from the heated coal to escape except through the ascension pipe "S," the upper end of which curves downward to dip into water in the gas-tight trough "V." This trough, called a "hydraulic main," receives the gas and a pipe leading from it is connected to an exhauster which draws the gas away as fast as it is made. By dipping the pipe from each retort into the water in the hydraulic main no gas can go backward through the ascension pipe "S" when the lid "L" is removed from the mouthpiece "M."

A coke fire is kept burning upon the furnace grate "G" and the heated gases therefrom pass, as shown by the arrows, around the outside of and completely enveloping the retort "R" which, becoming heated and remaining heated, transmits the heat through its wall to the coal "C" inside. The draft of the fire on grate "G" can be controlled by the damper "D."

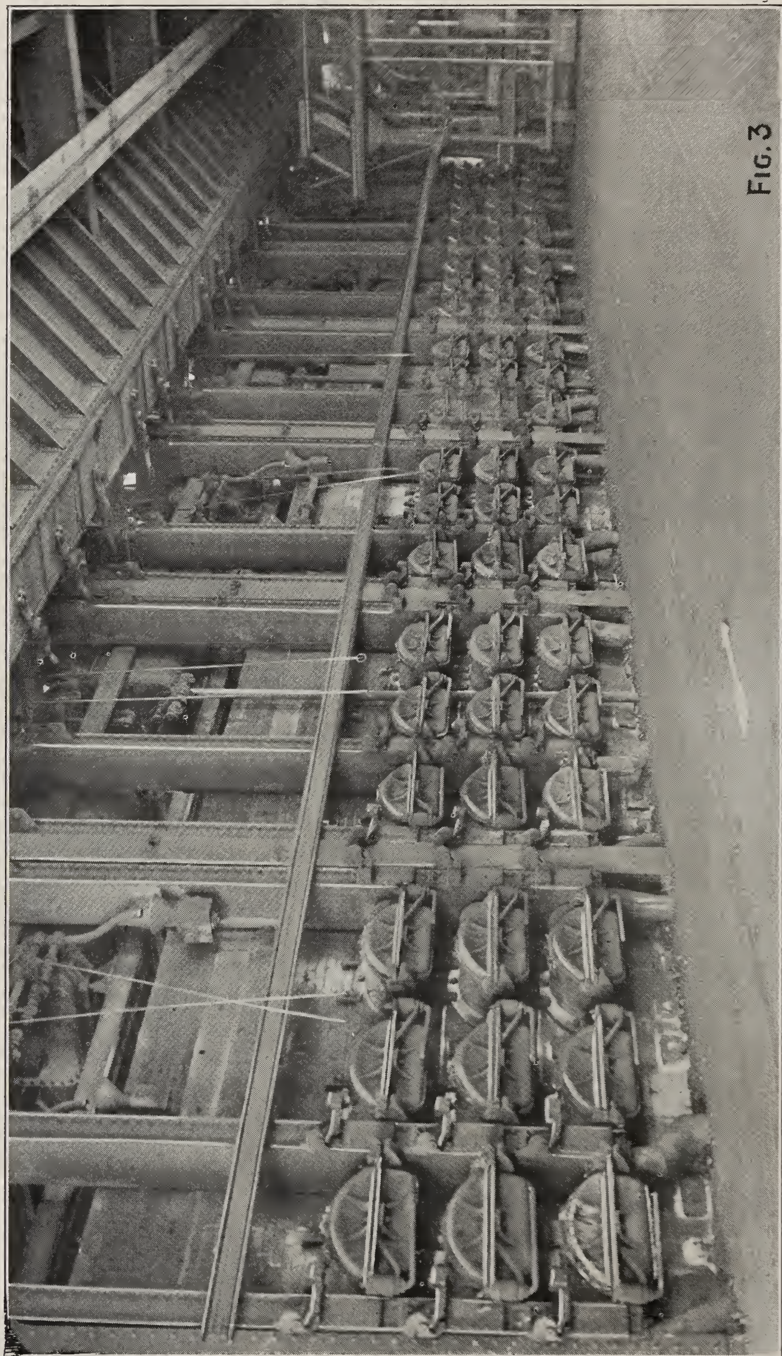
After the gas has stopped coming from the coal, the lid "L" is opened and the coke remaining in the retort is withdrawn through the mouthpiece "M;" a portion of this coke needed to maintain the fire on the grate "G" is then charged into the furnace and the balance is cooled with water and carried off to be sold or used in other places.

The charging of a retort is done at regular intervals and the amount of coal is carefully weighed for each charge. The retort as shown here would be about nine feet long, contain about 350 pounds of coal and would be charged every four hours. Other forms of retorts in use will hold more coal and be charged at longer intervals. Some hold as much as fifteen tons of coal and are charged only once in twenty-four hours. Figures 1 and 2 show the simplest form of single retort and would not be found in a present-day gas works in a single setting as shown in the illustration. In the gas works a number of retorts are heated by one fire, sometimes as many as sixteen. The present method of heating such retorts is not as simple as here shown but far more efficient in the saving of heat.

A setting of a number of retorts heated by one fire is called a "bench," and the benches are set side by side in a gas works as shown in Figure 3, there being nine retorts in each bench shown.

Where a large number of retorts are thus stacked together, they are discharged and changed in successive order so that the flow of gas from the hydraulic main "V" is continuous. Some of the tars and other materials will start to drop out in the hydraulic main "V" and the removal of the balance of these materials must be started at once before the gas cools further.

A pump called an "exhauster" draws the gas from the hydraulic main and forces it first into the condenser where it passes downward through a number of tubes which are surrounded by water and where by cooling it is separated from its tar and steam and some of the heavy oils; thence upward through the scrubber, consisting of a number of wooden trays, where it is brought in contact with a stream of water passing downward over the wetted surfaces, where the gas gives up its ammonia to the water; thence the gas



Benches of Nine Retorts Each in a Gas Works

Figure 4 shows the process for making purified coal gas.

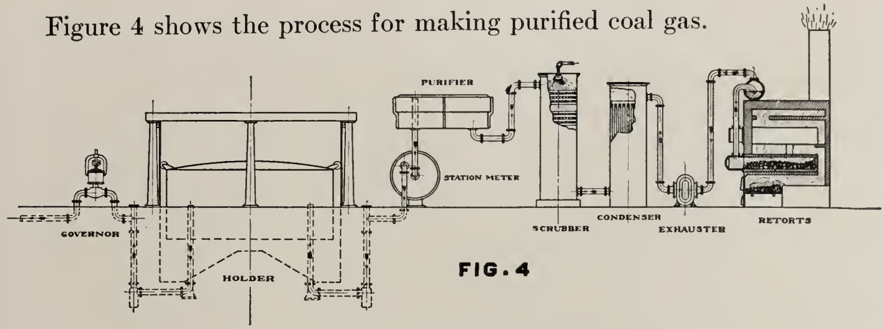


FIG. 4

Coal Gas Generating Apparatus

passes to the purifier where certain sulphurous impurities are removed by contact with oxide of iron (this is necessary because if allowed to remain in the gas they would cause discomfort and sore throat to people breathing the air in the room in which the gas was burned); thence through the station meter, where the amount of gas made is registered; thence into the holder. The material which is separated from the gas in the condenser flows out of the bottom of the condenser to a water-sealed pot (not shown) whence it goes to the tar storage.

The material removed by the water in the scrubber flows from the bottom of the scrubber into a water-sealed pot (not shown) and is conveyed to the ammonia well.

CARBURETTED WATER GAS:

There is one other way of making illuminating gas which will contain all the individual valuable gases contained in purified coal gas.

While the coal gas is made by breaking up (through the agency of high temperature, called destructive distillation) the chemically complex coal into a number of simpler parts, of which gas is one, water gas is made by a building up or synthetic process in which some of the component gases are made in one operation, others in another operation and all are mixed together.

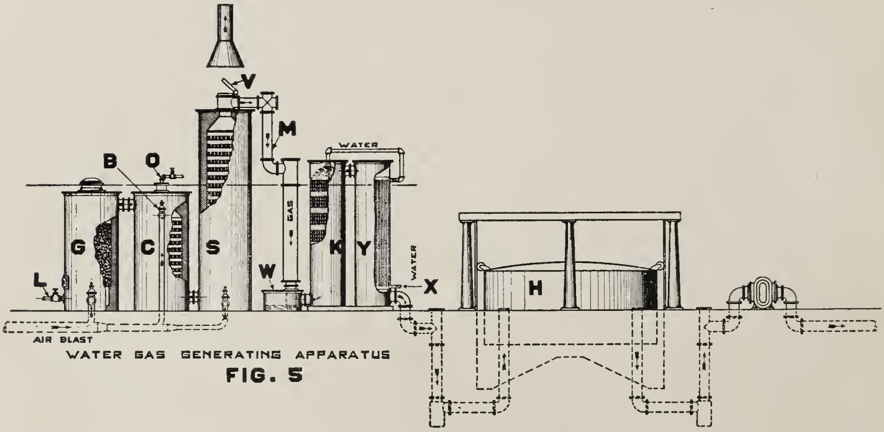
If a deep bed of fuel such as coke, or anthracite coal, is burned by forcing air under pressure through it, the products of combustion arising from the fuel will be found to be inflammable if burned while still hot by mixing them with additional air. This inflammable gas may thus be used to heat a mass of open firebrick, laid with openings between the brick and built up in superposed layers, and because of its cross-sectional appearance known as checker-brick.

If, when the bed of fuel and checker-brick gets highly heated, the admission of air is stopped and steam instead is passed through the hot coal or coke the steam will be decomposed, its oxygen will unite with the carbon of the coal forming carbon monoxide, its hydrogen will be set free, and these two gases (CO and H) will be given off the top of the fuel bed. These are called blue gases because while they give off heat in burning, they burn with a small blue flame and give only enough light to show that they are burning.

Hence, in order to insure a luminous quality to water gas, other gases are introduced at this point by the process called carburetting. These two hot

inflammable but unburned gases are passed through the hot open brickwork, and at the same time crude oil is showered down upon it. This oil is first vaporized and in further heating by passage through the brickwork its vapors are converted into fixed gases having luminous value which, even when later cooled to atmospheric temperatures, will not condense back to liquid but, remaining gaseous and in mixture with the blue gases from the fire, will pass from the apparatus as crude carburetted water gas. Some portions of the oil, small in proportion to the total quantity used, will be converted into tar instead of gas and the gas must be separated from these vapors of tars by cooling and washing. After this has been done the gas must be purified of its sulphurous constituents by passing it through purifiers as in the purification of coal gas previously described.

Figure 5 shows the process for making carburetted water gas.



WATER GAS GENERATING APPARATUS
FIG. 5

The anthracite coal or the coke is contained in the generator "G" which is filled to the height of about seven feet above the grate; firebrick is placed checker fashion in the chamber "C" and also in the taller chamber "S." Air is forced through a pipe called the air blast main shown dash-lined under the generator and can be led as desired (1) into the bottom of the generator, (2) into the top of the chamber "C," called the carburetter, and (3) into the bottom of the chamber "S," called the superheater. Each air inlet is controlled by a valve.

The fire in the generator being started, and the stack valve "V" at the top of "S" being opened, air is admitted to the bottom of the generator "G" and the heating of the fuel proceeds. As soon as the fuel gets heated to a bright red heat, the gases coming from the top of the fuel bed and passing over into the carburetter "C" can be burned if mixed with more air. This is done by opening the air blast valve "B," following which the firebrick in the carburetter "C" begins to get hot and the combined burning of these gases carries over into the superheater "S" and finally the burned gases pass out through the stack valve "V."

If the blast valve "B" at the top of the carburetter is opened wide all the gas can be burned in the carburetter which would then heat up rapidly, but if it is opened only slightly some of these gases will not get

air enough to burn until they meet with that air which is admitted and regulated through the valve in the lower part of the superheater. Thus the operator, by care in the amount of air he admits to each, can have the heating of the carburetter and superheater proceed as he desires.

The apparatus so far has not been making illuminating gas but has been getting its brickwork and fuel into a temperature condition to make it. When the heat in the fuel bed and carburetter and superheater has reached the proper degree

First: The air valves are all closed tightly. $H_2O + C \rightarrow CO + H_2$

Second: The stack valve "V" is closed.

Third: Steam is turned into the bottom of the generator and passing upward through the highly heated carbon, flows over into the carburetter top, no longer as steam but as carbon monoxide and hydrogen.

Fourth: The oil valve "O" is now opened and oil is sprayed down over the brickwork, vaporizing instantly and absorbing heat from the bricks, thus lowering their temperature. This cooling effect continues until unvaporized oil is carried over to the bottom of the superheater, at which time gas making should cease. In any case, when the oil is vaporized, it heats up rapidly and undergoes another important change. It will become "cracked" or "broken;" that is, it will change from a vapor that would upon cooling again become liquid into a number of simpler gases, which on cooling will remain as gases, except a small portion which will become tar.

This operation of "cracking" the oil whereby the molecules of the oil are broken up and rearrange themselves into simpler molecules is similar to the destructive distillation of gas coal previously described in the coal gas process.

The gases from the generator give no light and but moderate heat, the oil provides the gases that give both high heat and great light and the methane that gives little light and great heat.

So is water gas built up.

As to the balance of the process:

The stack valve "V" being closed, the gas reaching the top of the superheater in a very hot condition must be cooled. It passes down through the pipe "M" to the wash-box "W" where it bubbles through a water seal so devised as to prevent a return flow of gas, thence to the scrubber "K" filled with wooden open trays up through which the gas passes against water showered into the top of the scrubber. By this means the gas is washed clean from its tar and carbon particles, for whenever an oil is "cracked" there is liberated some fine carbon which floats as lamp-black in the gas. Thence the gas passes to the condenser "Y" where it is cooled by water surrounding the condenser tubes, the gas passing down through the tubes. A constant stream of cold water enters the bottom of the condenser at "X" and the hot water passes out through the overflow near the upper tube sheet to the top of the scrubber.

In the condenser the tar vapor accompanying the gas is cooled into liquid tar, which flows out of the bottom through a pipe dipping down into the liquid tar in the pot to prevent the escape of gas.

From the condenser the gas passes direct to a holder "H," called the relief holder.

The process of making water gas results in the cooling of the fuel bed and brickwork. The steam in passing through the fuel rapidly cools it to a temperature at which the oxygen will not properly combine with carbon, and the passage of the oil over the brickwork rapidly reduces the temperature below that temperature needed to properly "crack" the oil vapors. It then becomes necessary to stop making gas and this is done by:

First: Shutting off the oil flowing into the carburetter.
Second: Shutting off the steam flowing into the bottom of the generator.
Third: Opening the stack valve "V."

If it is necessary to add fuel to the generator it is done at this period of the cycle; the door at its top is opened and the fuel is shovelled or poured in. The ashes are removed from the door low down on the side.

Neither of these operations is required each time the gas making is stopped, so that usually the next step is to proceed with the reheating as previously described.

Water-gas making is a process wherein the apparatus is alternately heated by combustion with air during which time no illuminating gas is collected, and cooled by the steam and oil during which time gas is collected but no air is admitted. One complete cycle of gas making occupies about eight to ten minutes.

After the gas reaches the relief holder in an unpurified condition, it is pumped from that holder by the exhauster and forced through the purifiers, the large station meters and thence into the storage holders.

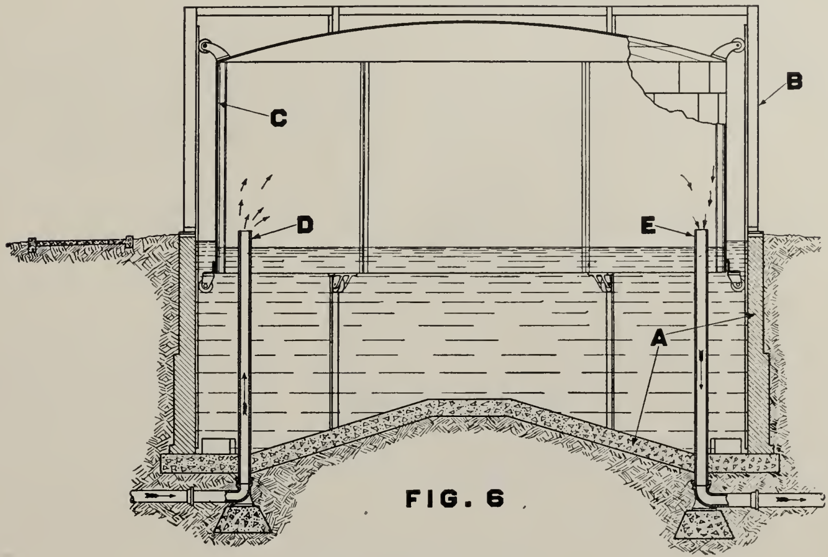
The term "water gas" is confusing to many, who have fancied that in some mysterious way a combustible gas was manufactured from water only. While some water in the form of steam is used in its manufacture, this water does not exist in the finished gas and is only used as above described in one step of gas making.

There is at present more water gas than coal gas made by American gas companies.

Water gas production is not accompanied with the large number of by-products which will always be found when bituminous coal is distilled to make coal gas. There are, however, some very valuable products resulting from water gas manufacture which are coming into use in many of the industries.

Gasometer

Figure 6 shows a simple one-section gas holder or gasometer and is here represented as if filled with gas. It consists of a tank "A," guide frame "B," and holder "C."



One-section Gas Holder

THE TANK "A":

This is, as shown in Figure 6, a pit sunk in the ground and made water-tight, by masonry or concrete walls on the sides and bottom. Extending up through the water-tight bottom and reaching above the level of the water in the tank are the gas inlet pipe "D" and the gas outlet pipe "E." Built into the bottom and located at equal distances around the bottom edge of the tank are "landing blocks" on which the holder lands when empty. Vertical guide rails made of steel are secured to the side walls of the tank and are equally spaced around the walls and form tracks or guides for the guide wheels fastened to the bottom edge of the holder.

THE GUIDE FRAME "B":

This consists of a number of vertical columns equally spaced and resting on the top of the side walls of the tank. The columns, usually built of steel, are connected to each other by horizontal girders and form a strong, wind resisting framework extending above and enclosing the tank. Each column has for its inner face a guide rail exactly vertical which forms the track for the guide rollers on top of the holder.

THE HOLDER, PROPER, "C":

This consists of an inverted cup built of sheets of steel riveted together and having a gas tight top or crown and a heavy rim of angle iron around the bottom. It is open, of course, at the bottom. Fastened to the bottom angle iron are brackets which carry rollers engaging with the vertical guide rails fastened to the sides of the tank, while the rollers shown above the edge of the top engage with the guides on the columns. In this way the holder is kept level while rising and falling according to the quantity of gas it contains. The rollers on the bottom are so placed as to avoid striking the landing blocks when the holder is "landed."

OPERATION OF THE HOLDER:

The holder being empty and resting on the landing blocks at the bottom of the pit, the exhauster forces the gas through the inlet pipe until pressure begins to accumulate in the gas between the holder top and the surface of the water. The first effect of this pressure is to depress the water level inside the holder, while it rises outside, as shown in the figuree As soon as this pressure is sufficient to overcome the weight of the holder. the latter begins to rise, the rollers at the top and bottom rolling smoothly and evenly on their guide rails. As more gas is forced in, no further increase in pressure occurs, but instead the holder rises to make room for the increased volume of gas.

If at the same time the gas can pass out of the holder through the outlet pipe "E" the holder will rise if the quantity of gas forced in is greater than that which passes out, and the holder will descend if the quantity passing out through the outlet pipe is greater than the quantity forced in.

If the gas is made at the same rate throughout the entire day and is forced into the holder in a steady flow, it is clear that during the hours when a smaller amount of gas is being burned than is made the holder will rise, and during the evening hours when a larger quantity of gas is being burned than is made the holder will fall. In this way the gas is stored in the holders during the hours of small consumption for use during the hours of large consumption.

Figure 7 shows how the quantity of gas that can be stored may be increased without increasing the size of the holder tank.

This is accomplished by making the holder in two or more sections, working one within the other like a telescope, and by increasing the height of the guide columns.

Let us suppose the holder empty,—that is, all of the sections resting on the landing blocks. If gas is now admitted the inside section "A," having a tight top, begins to rise from the landing blocks as gas is forced into the holder. To the bottom of this section a water-tight annular cup "B," running entirely around it, is fastened as shown. This cup is strong enough to carry the weight of the section "C" next to it, to which there is riveted at its top an inverted cup "D," the inside sheet or apron of which will reach over far enough to dip into the water of the cup "B" when enough gas has been forced into the holder to raise the inner section "A" to a level where its cup "B" will engage the inverted cup "D." As more gas is forced in, the inner section will continue to rise, lifting the second section with it while the depth of the water in the cup "B" will prevent an escape of gas

where the two sections unite. All holders in Philadelphia are built in this way, some having three, some four and some five such sections, or "lifts."

It is evident that after the first section has emerged from the water and the second section is hooked on, the weight of the metal and the water in the cup of the first section will add to the weight pressing down upon the gas and thereby increase the pressure of the gas within the holder and offer greater resistance to the inflow of gas from the works. Hence, as each section is filled and rises from the water there will be a step-up in the pressure of gas in the holder. It is also evident that the first or inner section must have sufficient weight in itself alone to give the pressure required to force the gas through the mains in sufficient quantity to give the best results. The added pressure, due to each section as hooked on, is therefore in excess and some means must be provided to reduce this pressure to the desired amount. This duty is performed by the gas governor which is interposed between the outlet of the holder and the inlet of the distributing mains.

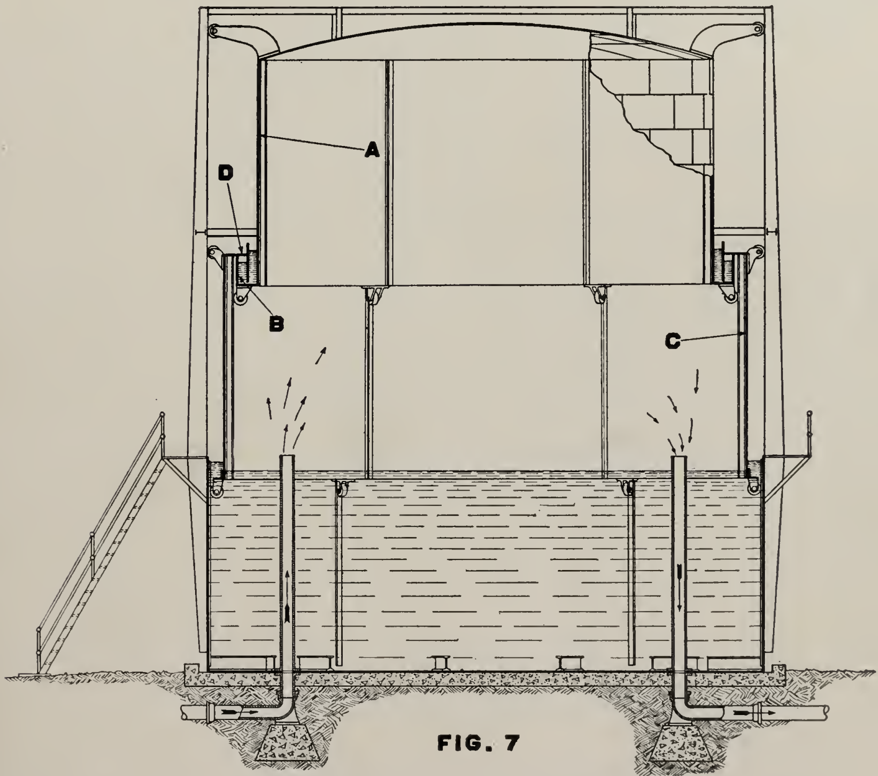


FIG. 7

Two-section Telescopic Gas Holder

The tank shown in Figure 7 differs from that shown in Figure 6. Here the tank is built of steel plates riveted together and set on a concrete foundation on the top of the ground. This form of tank has been used quite commonly in recent years.

PRESSURE GAUGE:

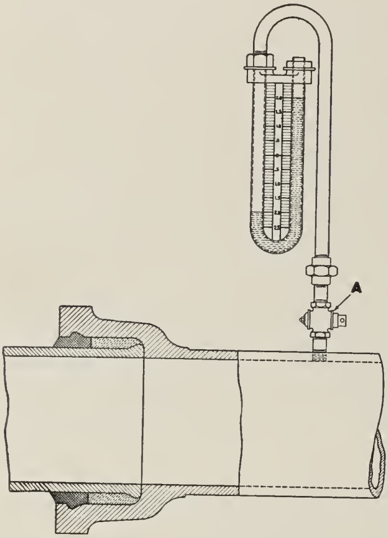


FIG. 8

Pressure Gauge and Bell and Spigot Pipe Joint

Figure 8 shows one form of gauge by which the pressure of gas is measured. It consists of a "U" tube made of glass, carrying a scale graduated in inches and one-tenth inches between the two legs of the tube. The top of one leg of the gauge is connected to the main by a pipe. The other leg is left free or open to the air. The tube is filled with water to reach in the legs to half their height. When the cock "A" is turned on, the pressure of the gas in the main, passing up through the connecting pipe, will push the water down in the connected leg and up a corresponding distance in the free leg until the weight of the excess column of water in the free leg will be balanced by the pressure of gas exerted on top of the water in the connected leg. The height that the water in the free leg stands above the height of the water in the connected leg is used to express the pressure exerted by the gas. To illustrate, if the water in the connected leg is pushed down two inches, and in the free leg up two inches, there would be a difference of four inches and the gas would be said to be exerting a pressure equal to four inches of water. This (4″ of water) is about average pressure of the gas in the distributing mains around the City of Philadelphia.

We have seen that the pressure of the gas existing in the holders is always somewhat greater than is required in the mains and that this pressure varies according to the amount of gas that is stored in the holder. This pressure, if not controlled, would cause serious inconvenience to the consumer. It would cause the gas to issue through the various burners at a more rapid rate, causing poor combustion, and no fixed adjustment of them could be made on account of the great variations in pressure that would ensue throughout the entire distributing mains. The pressure must be controlled in such a way as to maintain, for any desired length of time, a certain uniform pressure at the inlet to the distributing mains, and this pressure must be changed from time to time as the demands for gas vary. This is the province of the

GAS GOVERNOR:

A simple form of governor is shown in Figure 9: It consists essentially of a cast iron valve box (containing a double balanced valve) inserted in the main leading from the outlet of the holder to the street mains; of a cast iron water tank placed vertically over the valve box not necessarily directly upon it, with a bell made of sheet iron, similar to a small gas holder working in the tank, this bell being fastened to the valve rod so that as it rises and falls the valve rod moves with it. The valve rod continues upward through

the cast iron top of the water tank and has fastened to it a collar for the support of iron weights which can be put on or taken off as desired. Fastened to the top of the valve rod is a chain or chains leading to counterweight levers by which some of the weight of the rod and its appurtenances can be supported by the counterweights suspended from the other arm of the lever. A small pipe, "B," is screwed into the main at the outlet of the governor, passes in through the bottom of the cast iron tank and up through the water so that there will always be gas in the bell at the same pressure as at the inlet to the street main. This gas pressure in the bell, together with the counterweights, supports the weight of the valve rod and holds the valves steady without opening or closing, so long as the flow of gas is constant.

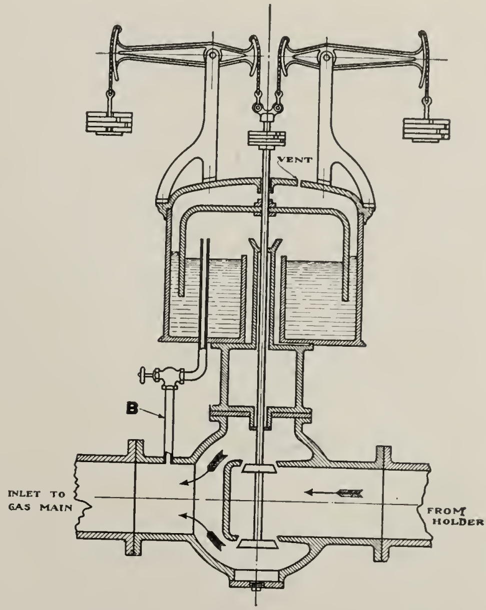


FIG. 9
Simple Form of Gas Governor

If the consumption of gas along the lines of the mains increases, the pressure in the main at the connection to the pipe "B" will tend to be reduced, the bell will lower, the valves will open wider and a large volume of gas will pass through into the main, thereby restoring or maintaining the pressure. As the consumption of gas along the lines of the mains decreases there will be a momentary increase in pressure at the connecting point of the pipe "B," the bell will rise and the valves will tend to close, thereby reducing the flow of gas into the mains. By this automatic opening and closing of the valves the pressure at the inlet to the mains can be kept uniform, so that when there is a large change in the quantity of gas consumed along the lines of the mains the governor will prevent changes of pressure in the mains.

The case may arise where there is a large increase in the consumption of gas at some middle point along the lines of the mains, in which event it is necessary to increase the usual pressure at the outlet of the governor in order that there shall be no material loss in pressure at the far end of the mains. To accomplish this, the governor valves being nicely balanced by the weight of the rod and its appurtenances tending to open the valves and the pressure of the gas in the holder and the counterweights tending to close the valves, then the weight of the valve rod and its appurtenances is further increased and the extra pressure desired will be required under the bell of the holder to restore the balance. In this way the pressure at the inlet to the mains can be maintained within such narrow limits as not to

be detected on the pressure gauge, and the attendant can add weights to the valve stem as required during periods of heavy consumption and remove them again during periods of light consumption.

In the larger cities where many hundreds of miles of mains are laid, the decrease in pressure from the governors at the works to the farther ends of the mains would be so great as to require extremely large, and therefore very expensive, mains to deliver the gas without great variations in pressure between the times of small consumption and large consumption. This can be obviated by locating additional holders at various points along the lines of the mains from which gas can be fed into the mains, thus maintaining a large flow of gas throughout the entire distribution system without great changes in pressure. These holders are supplied with gas by separate mains connecting them to pumps at the works by which gas can be pumped rapidly from the works under high pressure to fill the holders.

The pipes laid in the city streets for conveying water, gas or other commodities are called "mains."

THE MAINS:

The gas mains are made generally of cast iron in various diameters from two inches up to sixty, and in sections of twelve feet in length. A pipe laid in the ground of the city must resist corrosion or rust; it must not leak gas outward, nor if laid under water must it leak water inward; it must be strong enough to resist breaking by weight of the ground above or by movement of the ground due to frost or by crushing effect of heavy weights passing over the streets; it must be jointed together so as to resist being pulled apart or broken by contraction and expansion during change of seasons, particularly after lying for months under a coating of ice; and in going up and down hills it must be laid so that what condensation occurs in the mains will flow to drip pots inserted along the lines of the mains at the low points, from which the condensation may be pumped and carried back to the gas works.

The usual form of joint is shown in Figure 8 in which one end of a length of cast iron pipe terminates in an enlargement described as a bell, and the other end, called a spigot, is straight with a slight thickening of the iron at the end. This is known as a bell and spigot joint and the drawing of the pipe shows the method of joining the bell and spigot. The spigot end of one length of pipe is introduced into the bell end of the adjoining length, carefully centered and a packing of jute laid in the form of rope in several sections is forced into the bell end around the spigot and driven tightly home, leaving vacant a space of several inches around the opening of the bell. A roll of damp clay or other form of joint runner is then laid around the bell and molten lead is run into the vacant space between the mouth of the bell and the jute packing until it is entirely filled. The roll is then removed and the lead is driven up tightly with caulking tools and hammers by the main layers. This joint, which will permit of some movement without leakage, was generally used in the past. Other forms of joints are now in use and cement is largely used in place of lead.

The system of gas mains is a very important factor of the entire gas plant and represents a large percentage of the total investment. The size of the mains is determined both from investigation and experience, for it

is necessary, not only to pass the gas required when the mains are laid, but to provide for the additional gas that will be used with the growth of the business in that locality. Every street in the built-up sections of the city must have its gas main, and in some cases a main on each side of the street is required. They are proportioned in size so that pressures throughout the city will not change very greatly, and, what is more important, so that each consumer will not find a great variation in pressure during the different hours of the day and night. He should have nearly the same pressure when a small amount of gas is being used as he has when all his neighbors' and the street lamps are consuming gas from the mains.

With this in mind it is easy to understand that rapidly growing cities outgrow entirely the system of mains first put in. It is therefore necessary sometimes to build holders in sections of the city remote from the gas works which can feed their gas directly into those parts of the mains in which low pressures are likely to occur. When such holders are erected (and there are many in Philadelphia), it is necessary to run separate lines of large mains, which are entirely disconnected from the distributing system, through which gas can be pumped from the works at high pressures directly into these holders. In other places an additional supply of gas is obtained in the main system by connecting a separate main through which gas can be pumped at high pressures to the distributing system, and passing the gas from the pumping main into the distributing mains through a governor where the pressure can be reduced and maintained at the holder outlet.

If main laying were not done by careful, experienced workmen, it would be the source of great loss of money to the gas company and great annoyance to the citizens of the city because of leaks, unpleasant odors and frequent digging up of streets, and sometimes by frequent renewal of mains because of broken pipes. Great care must be exercised in leveling and packing the soil underneath the mains and supporting their weight and refilling and tamping the ground so that every portion of the mains may rest upon a tightly packed and immovable bed at a sufficient depth below the level of the street so as to be unaffected by the passage of unusually heavy loads over the roads.

Gas, from the time it leaves the works until it reaches the burners of the consumers, except when stored in outlying holders, is not subject in continuity of its supply to those changes in atmospheric conditions that cause trouble to many of the other companies distributing their product under city franchises; nor is the supply of gas disturbed, as is frequently the case with the supply of water, by reason of broken pipes and large connections. When a water pipe leaks it is apt to wash the foundation from under it. The water pipe is exposed to heavy pressures due to the water on the inside. The sudden movement of large quantities of water is apt to put unusual strains on the pipe. From all such effects the supply of gas is undisturbed. The holders are strongly built for their purposes, are not affected by lightning, can be kept unaffected by snow or sleet or other disturbing causes, and have stored in them large quantities of gas made ready for distribution through the undisturbed mains of the city, capable of supplying the consumers for many hours if it were necessary for any reason to stop the manufacture of gas.

In large cities, such as Philadelphia, where the beds of the streets are occupied by a number of mains and other apparatus of public service companies, a defect that develops in one system may reach and cause trouble and sometimes discontinuance of supply through the other systems. Electricity leaking from electric mains, conduits or tracks may affect and cause leakage in either gas or water mains. Water leaking in considerable quantity from water mains may wash the foundations from under the other systems. It is necessary, therefore, to have in well regulated companies in the larger cities a large force of expert men devoting their entire time to the duty of maintaining the system of distributing mains adequate for the supply to all consumers, ready to repair breaks and to make such changes as are necessary to keep the mains tight and resting properly in their beds. Pressures are observed in the mains at all hours of the day and night. Men called "line walkers," as on railroads, travel daily along the lines of the mains and are quick to detect any leaks or possible causes of disturbances by excavations made by others across the beds of the mains.

SERVICE PIPES:

In front of each house a hole is drilled in the top of the main and a pipe large enough to provide gas for all probable needs is led into the premises under the sidewalk. This pipe is called a "service." It is generally of wrought iron or steel with screwed connections, and to its end in the cellar of the premises a meter for measuring the gas used in the premises is connected.

METER:

If a storekeeper wished to draw out of a barrel a liquid such as molasses, cider or oil and to know exactly the quantity he drew out, he would fill a measure holding one quart or one gallon a number of times, and he would keep a record of that number. If he measured the quantity exactly he must have observed four things in the process:

First: That he filled the measure each time to the line which marked exactly one quart or one gallon.
Second: That he completely shut off the supply.
Third: That he completely emptied the measure before opening the supply again.
Fourth: That he kept an accurate account of the number of measures so filled and emptied.

This is a true method of measuring liquids, but it is clear that one additional step must be taken in the measure of the gas supplied to the consumers, because in the latter case the supply can not be interrupted during the period of emptying the measure. The dry gas meter in a similar way measures the volume of gas delivered through it, but instead of one measure being alternately filled and emptied, in the meter there are four of these measures in operation continuously, one or more filling while there is always at least one emptying. This insures a continuous delivery of gas.

These four measures do not have to be of exactly the same size, but each of them must be filled in the same way every time so that each com-

plete round of filling and emptying of the four measures shall measure exactly the same quantity of gas. Instead of keeping tally of the number of times that each is filled, as in the case of the grocer, it is necessary in the meter that the amount of gas passed shall be automatically registered and this is done on the meter dial.

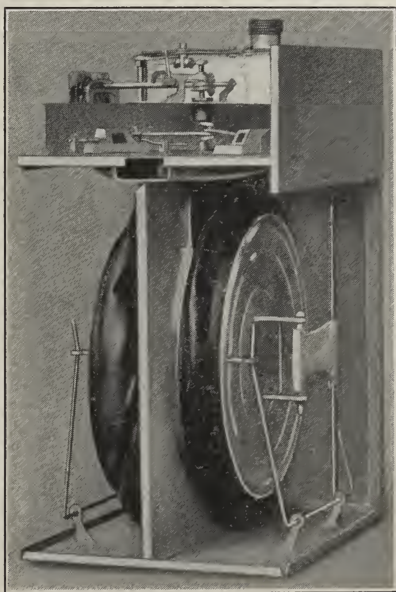
Figure 10 shows the case and the four compartments.

Figure 11 shows the mechanism operating in these compartments.

Fig. 10

Dry Gas Meter (Case)

Fig. 11



Mechanism for Operating Dry Gas Meter

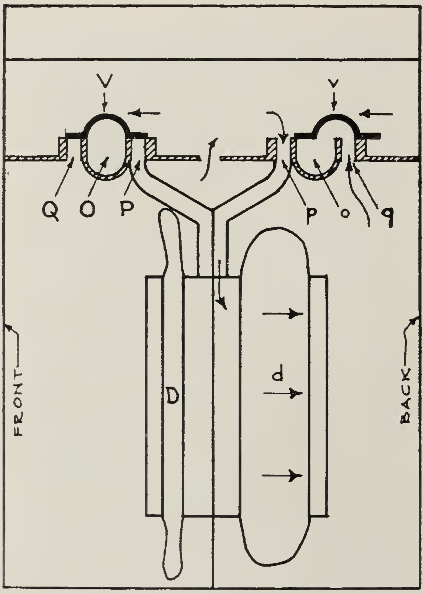
The two lower compartments are the measuring compartments and the two upper compartments contain the valves and the system of levers, shafts and gears necessary for filling and discharging the measuring compartments and for registering on the dial the amount of gas that has passed through the compartments.

In each of the lower compartments a thin metal disc is connected to the central partition by means of a band of soft, collapsible, oiled and gas-tight leather. The metal disc is kept vertical in its movements by means of wire guides and by the wide "flag" lever, by which its movement is conveyed to the vertical rod which extends into the upper compartment and operates the valves.

Gas is alternately and automatically admitted and expelled, first from the compartment inside the bellows and, second, from the one outside of the bellows. The operating force, it will be understood, is the difference between the pressure in the mains due to the pressure from the holder, and the pressure on the outlet of the meter, due to opening of a burner cock.

As gas is admitted to the compartment inside the bellows, the bellows open out and the metal disc is forced toward the front of the meter, the movement is communicated to the vertical shaft, which in turn operates the valves in the upper compartment and also the gears connecting with the dial on the front of the meter. While the compartment is filling with fresh gas from the inlet duct of the meter, the compartment outside of the bellows is emptying into the outlet duct of the meter. The vertical shafts in each of the lower compartments combine through levers to operate the two valves.

Fig. 12



Measuring Compartments and Valves of Dry Gas Meter

Figure 12 shows one position in the movement of the measuring compartments and the valves of the meter. Here the gas is just finishing being discharged from the inner compartment of the left hand bellows, and the outer compartment is completely filled with gas. The inner compartment of the bellows on this side is entirely empty and the exterior compartment of the bellows is entirely closed and there is no communication with the inlet or outlet of gas to either compartment. In other words, one measure is entirely empty and the other is entirely filled. The supply from the grocer's barrel is closed off from these measures.

On the right hand side the interior of the bellows is filling and the exterior is discharging. While the interior is filling there is no opportunity for the gas to be discharged from this measure or compartment, and there is no opportunity for fresh gas to enter the compartment that is being discharged.

The motion of the disc on the right hand side is being conveyed by means of the "flag" arm to the vertical shaft, which is so connected as to operate the valve "V" for admission and discharge of gas to the left hand compartment. The valve is about to move so that the port "Q" will connect with the discharge port "O" and the port "P" will be opened to the flow of fresh unmeasured gas into the interior of the bellows "D."

Meanwhile on the right hand side the gas in the outer compartment is passing out through the port "q" into the discharge port "o," while the port "p" is now entirely open to admit gas to the interior of the bellows "d," which is about half filled. The valve "v" is about to begin to close the port "q" from measured gas and the port "p" from fresh gas, but gas will continue to flow through these ports until the valve has moved far enough to entirely cover them or until the inside of the bellows "d" has been completely filled, by which the time valve "V" on the left will have moved so that the port "P" will be fully opened for admission of gas to the bellows "D," which will then be half filled or in the same condition

as shown in the compartment "d" in the figure, and the port "Q" will be wide open for the discharge of gas from the outer compartment into the outlet "O."

It is absolutely essential for the accurate measurement of gas by this method that the bellows shall contract and expand to exactly the same extent for each emptying and filling. The meter dial registers the number of times that these compartments are filled and emptied, and it expresses that record in terms of cubic feet of gas passed.

METER PROVER:

Each meter after construction is tested for leakage, for ease of working parts, and finally is connected to an instrument called a "meter prover" for adjusting the operation of its valves, so that the passage of a trial number of cubic feet as exactly measured by the prover shall agree with the registration shown on the meter dial.

The meter prover consists of a very accurately constructed small holder having a capacity of about five cubic feet, moving up and down in a tank of water and provided with a scale showing accurately the changes in capacity for changes in lineal height.

These provers are the working "capacity standards" by which the accuracy of large numbers of meters is tested. They have the merit of quick operation within the limits of accuracy necessary.

The calibration of these provers as to their accuracy before use is, however, a longer process, requiring exact control of the equal temperature of room, containers, water and measuring fluid (either air or gas). The calibration is effected by a Cubic Foot Bottle, bulbous in shape and made of copper. This bulb draws down to narrow glass tubes connected at top and bottom, upon which are scribed two fine lines. At a fixed temperature and pressure the contained volume of the bottle between these two lines is exactly one cubic foot.

Air is measured first by the bottle, one cubic foot at a time, and then displaced by water and forced into the prover. In this way the vertical scale on the prover is calibrated in integral cubic feet, after which the subdivision into one-tenth cubic feet is effected by equal parts.

The bottle itself has its volume determined with the most extreme care by the Bureau of Standards at Washington which certifies its accuracy.

In the meter just described the amount of gas is observed at regular intervals by reading the dials and a bill is presented to the consumer for the amount of gas consumed since the previous reading; that is to say, from the total amount of gas that has passed the meter, as shown on the dial at the time of the reading, the total amount of gas that had passed through the meter, as shown on the dial at the time of previous reading, is subtracted and the difference is charged to the consumer at the rate fixed per thousand cubic feet.

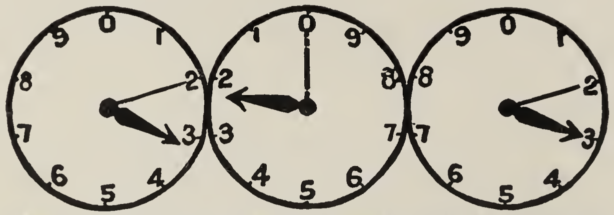
HOW TO READ:

The method of reading a meter is shown on each gas bill presented, as illustrated in Figure 13. By means of the instruction there given each consumer may, at any time, determine the rate at which he is using gas.

Another form of meter, known as "prepayment meter," is one in which

a coin placed in a slot of the meter will permit by mechanical arrangement, a fixed amount of gas, equal in quantity to the amount that the coin would purchase, to flow through the meter, when the meter automatically locks and no more gas will pass until another coin is put into the slot.

Fig. 13



Each division on the right hand circle denotes 100 feet, and on the centre circle, 1,000 feet, and on the left hand circle, 10,000 feet. To take a statement from the meter, begin at the left and set down the *lowest* figures next to the hands on each circle, which in the diagram are 8, 2 and 8; showing the statement to be 32,300. If at a former observation the hands were at the *dotted* lines, the statement then was 20,200; and the difference between the two statements is the amount of gas consumed—viz., 12,100 cubic feet.

Explanation of Gas Meter Dial

The outlet of a meter is connected to the house piping, which generally consists of one or more pipes rising from the main pipe in the cellar to the different floors, according to the size of the house, lateral pipes being run between the joists of the ceiling or along the side walls and coming through the plastering at certain places, to which the fixtures are attached. Another line of pipe will probably be run to supply other appliances used for burning gas besides lighting, such as gas cooking stoves, water heaters and in industrial establishments for the large number of appliances in which gas is used.

Before gas is supplied to a house, application must be made at the gas office to have a meter connected and the gas turned on. The house piping is first put under pressure by the company's inspector by means of an air pump, all other cocks except to the pump being closed and a U gauge being placed in the line to indicate the pressure. If the piping is tight the pressure as shown by the gauge should remain at the height indicated when the pump cock is also closed. If, however, the piping leaks, the falling column in the gauge indicates it, and such leak must be found and stopped before gas will be turned on.

METHODS OF USING GAS:

The term "burning," as applied to gas, means the union of its carbon and hydrogen with oxygen obtained from the air,—air containing about four parts nitrogen and one of oxygen. This, called oxygenation or oxidation, is a chemical union giving off heat which is a form of energy, and it is this heat that is used to produce the results obtained in many different methods of using gas. These methods of burning may be divided into four classes:

First: That in which gas and air ($O + N_4$) do not mix prior to the point of ignition.

Second: That in which gas and part air ($O + N_4$) do mix prior to the point of ignition.

Third: That in which gas and total air ($O + N_4$) do mix prior to the point of ignition.

Fourth: That in which gas and O (only) do not mix prior to the point of ignition.

First: If a thin, flat stream of illuminating gas is allowed to issue from a burner, such as a lava tip (Figure 14), it will, when ignited, burn with a bright, luminous flame. The oxygen of the air in contact with the surface of the stream of gas can only combine with the carbon and hydrogen of the gas when they have been raised to a certain high temperature; they will not combine when cold. This temperature is momentarily applied with a lighted match, or an electric spark, or a small burning jet of gas called a pilot light. But as soon as oxidation begins, the heat evolved from the chemical union is more than sufficient to maintain the temperature necessary for continued oxidation of the gas flowing from the burner.

Fig. 14

Lava Tip Gas Burner

The gas is now burning only on the very thin outer surface of its stream where the air can touch it and the temperature of this surface is very high—over 3000° Fahrenheit. This, in turn, heats the unburned gas inside the surface to almost the same temperature.

All substances simple and complex, including this illuminating gas, exist in the unit form of molecules which may be considered as restraining envelopes. Within these tiny envelopes in a high state of activity are the atoms, the various ways in which they pair off or combine giving the peculiar character to their enveloping molecule, by which in turn each substance is distinguishable from all other substances.

The activity of these atoms is increased by raising their temperature, and for each kind of molecule there is a temperature at which it disrupts and no longer can confine its captive atoms.

It is, then, a chemical fact that the molecules of the gas, made up of the union of atoms of carbon and hydrogen, cannot hold together at the above temperature and in consequence the hydrogen is liberated as a gas and the carbon turns into finely divided particles, and if cooled at this stage by putting a cold substance, such as a nail, into the interior of the flame, the nail would soon be covered with these fine particles of carbon, like lamp-black. It is these fine particles of carbon released inside the stream of gas beyond the reach of oxygen, and being heated by the com-

bustion on the surface, that become incandescent and give the luminous effect to the flame. Thus an incandescent carbon light is as truly formed as by the electric method in which the carbon in a filament is heated by electric current and the oxygen kept away by a wall of glass instead of by a wall of incombustible gas. As soon as these free atoms of hot hydrogen and carbon reach the surface, however, where oxygen may be had, they are instantly converted into water vapor and carbonic acid and disappear as products of combustion.

The number of carbon particles thus existing in the flame and the temperature to which they are heated determine the amount of light the flame produces. For nearly seventy years after so-called illuminating gas was first introduced it was used almost exclusively for lighting by means of burning it in jets as just described; and the value of the gas depended entirely on the amount of light that was produced by the burning of a certain quantity of gas in a certain time, five cubic feet per hour being selected. The amount of light so produced is expressed in terms of the light of a certain kind of candle made of sperm and burning 120 grains per hour,—the kind of sperm, the kind of wick and method of burning being all very minutely described by a committee representing the House of Parliament of England. It is called the British Standard Candle.

The instrument by which the intensity of light produced by any light source is measured is called, as the name implies, a photometer. A description of this instrument will be found in the appendix.

The use of luminous jets of gas is not confined to purposes of illumination. Many heating stoves use this method because of the radiating effect of the heat from the particles of incandescent carbon. With proper reflectors advantage can be taken of this to give a widely diffused heat.

Second: The luminous flame from a jet as just described is unsuited for a number of uses of gas because of several reasons:—its tendency to deposit unburned carbon whenever the flame comes in contact with a cooler surface, and also because a considerable portion of the heat evolved in the form of radiant heat is not best suited for application to the purposes required.

Therefore, the principle of what is known as the Bunsen burner is put into use for the greater number of devices in which gas is used, such as water heaters (Figure 15), some forms of gas heating stoves, most forms of gas cooking stoves and in the Welsbach or incandescent mantle lamps. By this means the gas is mixed on its passage to the burner, and before its ignition, with about three times its quantity of air. This is called primary air. This has the effect of presenting the mixture at the opening of the burner in such

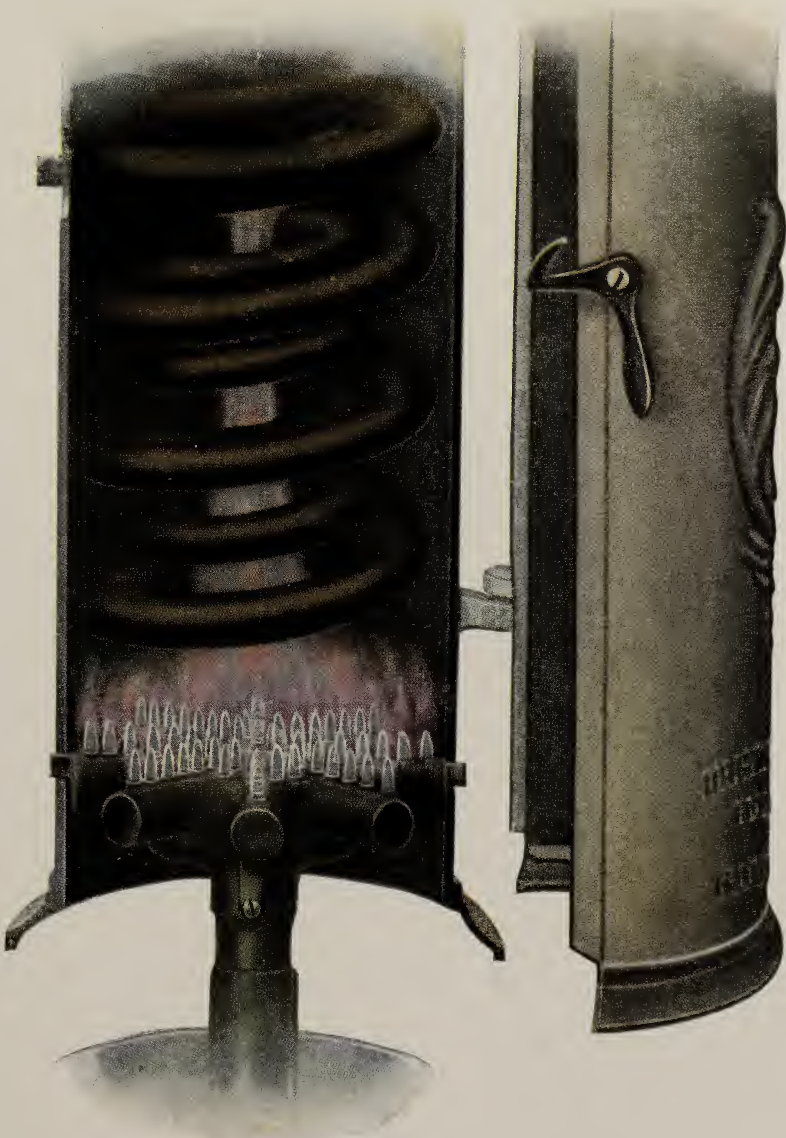


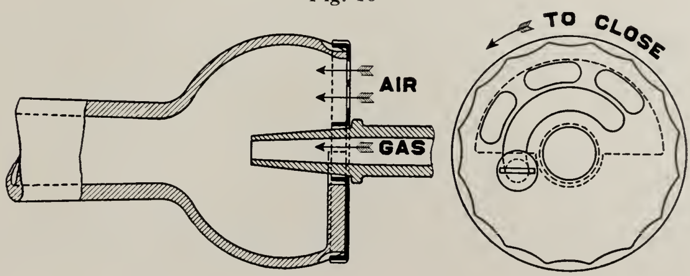
Fig. 15

Water Heater, Showing Proper Combustion of Gas by Use of Bunsen Burner

form that the carbon is partially oxidized to carbon monoxide and does not appear in a finely divided state, but on the other hand, when the remainder of the necessary air (called secondary air) is supplied, burns to a short blue flame which has the advantage of allowing great concentration of heat to any point desired and which will not deposit carbon on any cold surface, but which will, if a cold surface can be continued in the flame, cause some of the gas to pass off unconsumed.

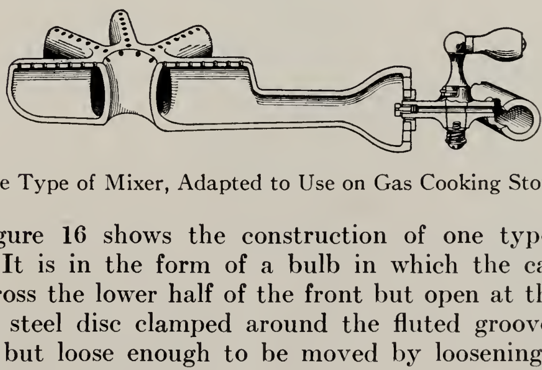
The method of introducing the gas and mixing it with the proper proportion of air for its complete combustion is illustrated in Figures 16 and 17:

Fig. 16



Details of Mixer, Bunsen Principle

Fig. 17



Same Type of Mixer, Adapted to Use on Gas Cooking Stoves

Figure 16 shows the construction of one type of air mixer. It is in the form of a bulb in which the casting is solid across the lower half of the front but open at the upper half. A steel disc clamped around the fluted groove of the casting, but loose enough to be moved by loosening the set screw, has openings cut in it through which the air is admitted to the mixer. The gas inlet is in the center of this disc and the disc can be turned around the gas inlet in such a way as to change the size of the opening for the admission of air. The stem of the gas inlet orifice is pushed into the mixer so that the gas, entering under pressure, induces or pulls in a flow of air through the openings, and the air and gas are usually mixed in the proportion of about three volumes of air to one of gas in their passage to the burner.

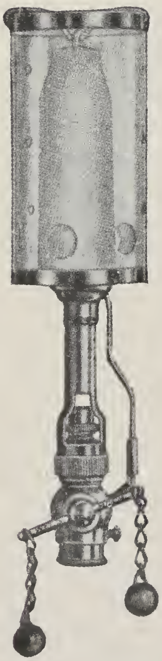
Figure 17 shows the same type of mixer adapted to use on gas cooking stoves. On one end is the mixer and at the other the star-shaped burner from the small holes

of which the mixed gas and air burn in jets about three-quarters of an inch long in a blue flame (as shown in Figure 15). The closing of the cock through which the gas is supplied will reduce the pressure and, therefore, reduce the amount of air that is drawn in, so that the mixture will be maintained in about the proper proportions. If more than this proper amount of air is admitted there will be a small explosion and the gas will be ignited in the air mixer, which is undesirable since it heats up this portion of the apparatus rather than the utensil placed for use. If not enough air is admitted, luminous tips will begin to show on the edge of the small jets and the bottoms of utensils will be blackened. It is, therefore, necessary that the gas companies from their experience should set the air mixer so as to give the proper quantity of air, and this should not then be moved except by some experienced person.

In the Welsbach burner another well-known form of mixer is used, but the principle upon which it operates is the same.

The Welsbach Lamp

Fig. 18



Upright Mantle

The Welsbach mantle lamp has superseded the use of the lava tip to such a very large extent that in practice the value of a gas may be said to depend at the present day, not upon the amount of light that will be obtained without previous mixture with air, but almost entirely upon its heating value, since it is the heating value that becomes effective in producing light in the Welsbach lamp. In the Welsbach lamp the gas is also mixed with two and a half to three and a half times its quantity of air before reaching the burner, and the burner is so designed that the shape of the flame will coincide with the shape of the mantle, so that the mantle will lie exactly in the area of highest temperature of combustion.

It was the discovery of Auer von Welsbach that the oxides of the rare elements of thorium and cerium when mixed together in a correct proportion and made up into the form of mantles gave a surface of exceptional brilliancy when heated in the Bunsen flame.

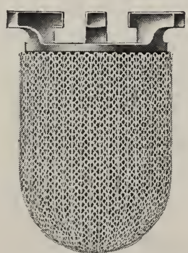
There are various types of Welsbach lamps, suited to the needs of places which are to be lighted. In general these are named in accordance with the direction which the mixture of gas and air travels. If it travels (1) upward it is called an upright lamp; if (2) downward, an inverted lamp; some mixing tubes for use with clusters of mantles are (3) horizontal discharging downward, the attached mantles being of the inverted type; and finally (4), the newest

type of lamp devised to replace the open-flame burner has an upright Bunsen tube with inverted mantles.

Like other gases, when illuminating gas is heated it occupies a larger volume without increase in weight. This adds buoyancy to that which it already has as it is lighter than air, and it tends more strongly to rise. For this reason it can be seen that the behavior of the mixtures in a hot upright Bunsen tube and in a hot inverted Bunsen tube will be different, and therefore the construction will be somewhat different as well as the manner of placing the mantle. In general, if the point of combustion is higher than the point of admitting primary air, the hot mixture is aided in its upward flow toward the mantle. If the point of combustion is lower than the point where primary air enters, the hot mixture is somewhat hindered in its downward flow to the mantle. One effect of this is to make the flame shapes different, and hence also the mantle shapes which must conform to the flames.

The upright mantle (Figure 18) is long, cylindrical with a vent hole at its top, and rather close fitting around the burner; its maximum light is given off, therefore, in a horizontal direction.

Fig. 19



Inverted Mantle

The inverted mantle (Figure 19) is shorter, larger in diameter, hung with an annular opening around the burner, and is dome shaped so that its maximum light is given downward at an angle where it is most desired. This accounts for the popularity in the past of the inverted lamp.

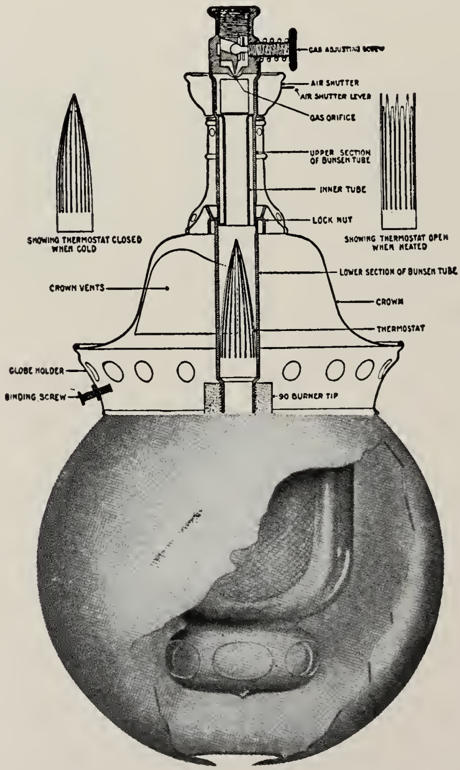
Both types of mantles, it will be noted, are suspended from above, as mantles are quite soft and flexible when incandescent, and would not then support their own weight if stood upright.

All types of mantle lamps may now be had with pilot-lighting attachments for convenience of ignition. This is accomplished by leading gas through a small metal tube to a position where it discharges upon or close to the mantle and then arranging the valve control to the lamp that when the main supply is turned off the pilot supply is on, and

vice versa. The extinguishing mantle then lights the on-going pilot, or the pilot lights the mantle, depending on which way the valve is turned. Such an arrangement is known as a "by-pass valve" (Figure 18).

It is apparent that after a lamp has been turned off for some time its Bunsen tube will be filled with air. Hence, when gas is again turned on there must come a moment when the entering gas and the loitering air form an explosive mixture, and the flame would tend to flash back to the orifice whence the gas issues near the primary air ports. Such a flash-back will occur unless the entire plug of mixture in the burner tube is moving faster than the velocity with which the explosive wave travels back, or else, a gauze like that used in an Humphrey Davy lamp must be inserted which will so lower the temperature that the flame cannot ignite back through it. Usually gauzes are placed, and the remedy is simple and effective with upright burners.

Fig. 20

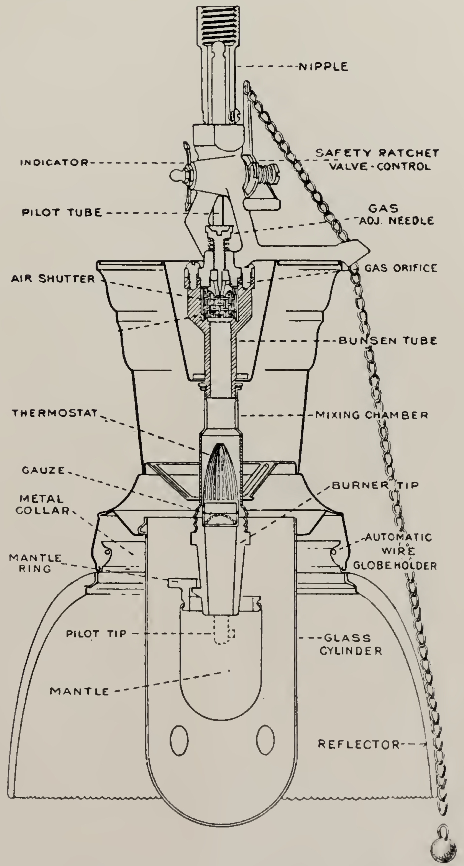


Details of Inverted Mantle Light

The case is not so simple with inverted burners, however, because as before stated they already have a hindrance to their downward flow of hot mixture, particularly at low gas pressures, and an added stoppage would make the lamp inefficient. To meet the need at this point a thermostat was devised, as shown in Figure 20, which acts as a sort of gauze at the time of ignition, but as the lamp gets heated, rapidly opens to permit the full flow of air for a correct mixture.

Figure 21 shows a larger type of inverted lamp, used in industrial and commercial lighting. This lamp has a metal stack which serves to increase the draught by which secondary air is supplied to the outside of the mantle.

Fig. 21

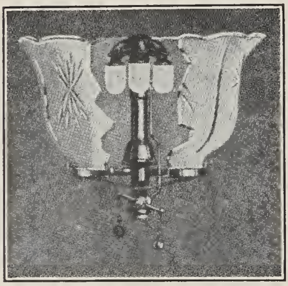


Larger Size Inverted Mantle Lamp

Still larger inverted lamps called arc lamps are in use, in which two, three, four or five inverted mantles are clus-

tered inside one globe, and the stack still further elongated for increased secondary draught.

Fig. 22



Upright Bunsen Burner with Inverted Mantles

Figure 22 shows the newest type of lamp with upright Bunsen tube, yet fitted with inverted mantles. The peculiarities of this lamp are: (a) Its ability to replace, without further equipment, an open-flame burner; (b) its high efficiency in entraining over four volumes of primary air, due to design of its inside Bunsen curvature; (c) that the mantles screw on instead of hang; (d) that the entire mantle head is removable and interchangeable like electric bulbs. It is thus seen that many sizes of low-pressure gas mantle lamps are available. In general, these lamps yield about twenty candle power for each cubic foot of gas consumed.

There is a sufficient variety of sizes to meet every need from a small home table reading lamp to a lofty-mounted high-candle-power factory lamp. And it is well to remember that under artificial illumination where much of our work and recreation are taken, good lighting should be insisted upon,—for health and nervous tone are strongly influenced by the way we use our eyes. Illumination should be adequate, of good color, steady, and either properly diffused or directed.

If any means can be used to increase the temperature of the Bunsen flame and hence of the mantle, then the light given by the mantle increases at a far greater ratio than that of the temperature. Any method by which an increased quantity of gas can be burned within the same flame volume must result in a greater release of heat and hence an increased temperature. One way of accomplishing this is when, of the total air required for complete combustion, an increased percentage of it is pre-mixed as primary air.

In every mixing of gases for combustion, a certain time is required for such a diffusion of molecules throughout the mass as will enable the imprisoned atoms upon their release to effect quickly their new chemical union. It is this time which is saved to combustion by the pre-mixing of air, and it is this increased speed of releasing and utilizing energy which raises the temperature.

Three means may be named by which this increase in the primary air ratio may be gained, but they require the use of some power other than entrainment by low-pressure gas:

1. The gas pressure must be mechanically increased, by which a greater proportion of air entrainment results.

2. Air pressure must be mechanically supplied, by which any proportion desired may be had.
3. Air and gas must be mechanically mixed and delivered to the burner.

1. The first means is much used in many industrial plants where gas is burned under as high as eight pounds per square inch in order to get highly concentrated heat covering a considerable surface. It is also found that mantle lamps designed to use gas under two to three pounds pressure give from two to three times the amount of light per cubic foot of gas as is obtained under the usual main pressure of about two ounces.

In the case of Welsbach street lighting, where high-pressure gas is used, a separate main carrying gas at high pressure to the lamps must be provided. When this is done it is possible to light and extinguish all of the street lamps from a central point, the same as the arc electric lights are lighted and extinguished. In Philadelphia a sample of such high-pressue gas lighting can be observed in the posts in front of the offices of the gas company at Broad and Arch Streets.

2. This system using air compressed by water or other power is correct in principle, but makes uniformity of results dependent on two power sources instead of one.

3. The pre-mixing of gas and air by means of a mechanical mixer, and the delivery of this mixture to burners safeguarded from flash-back by approved devices is one of the latest methods of utilizing gas and is gaining in popularity. It can be seen that this means may theoretically be pushed to the point of supplying all of the air needed for complete combustion, which would, for a number of appliances, accomplish what is automatically done for itself in the case of the gas engine, as described in the next method.

Third: Coal gas and water gas require for their complete combustion from eight to twelve times their volume of air, the exact proportion depending on the proportion of the different individual gases that enter into the composition of illuminating gas. For instance, hydrogen requires a smaller volume of air than is required for the same volume of methane.

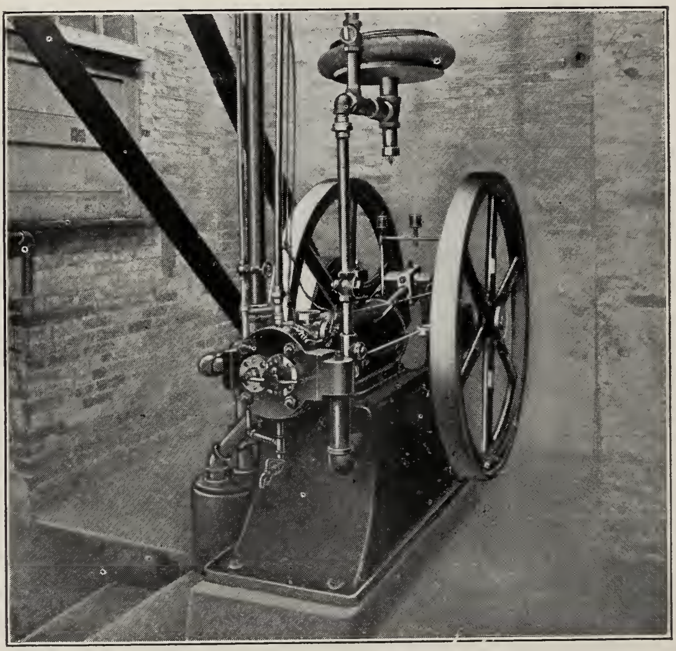
We have seen the effect of burning gas without previous mixture with any portion of air, and the effect of burning gas after passing it through an air mixer in which about three times the volume of air is mixed with the gas.

If *all* of the air necessary completely to burn the gas were thoroughly mixed with it previous to ignition as primary air, the combustion, of course, would, in a given chamber, be instantaneous and would constitute what we call

an explosion. It is this principle which is used in a gas engine or in all so-called internal combustion engines in which the proper mixture of gas and air is admitted to the cylinder, the port of admission closed, and ignited with an electric spark.

Gas engines are used in large quantities, particularly where small units for power are required. They can, with safety, be set in almost any place and have the great advantage over a steam engine and boiler in the small amount of space required, small weight of apparatus, no dust or ashes and freedom from danger of fire.

Fig. 23



Gas Engine

In Philadelphia such gas engines are used to operate the large pumps to force water at increased pressure through the high-pressure water mains for extinguishing fires.

Fourth: Another method of burning gas consists of supplying pure oxygen to the flame instead of obtaining oxygen from the air. This gives a short flame of very high temperature and is used for a number of purposes, such as cutting through steel plate, brazing, welding, etc.

In the first three methods described atmospheric air was used for supporting combustion, and with each volume of oxygen in the air thus used there were supplied also four volumes of nitrogen, an inert gas which had to be

raised to the same temperature as the other products of combustion, and passed off with them, removing a large quantity of heat by the process known as convection. Not only this, but it enlarged the flame volume and, therefore, defeated the localizing of combustion by which high tem-

Fig. 24

Test of High -pressure Water System. Power Supplied by Use of Internal Combustion Gas Engines

perature is achieved. In the use of this method the gas and oxygen are supplied by two separate tubes, the mixing not taking place until very near the point of combustion. Figure 25 shows the apparatus in use and indicates the small volume to which the flame is concentrated.

In the first method of burning gas for illumination without previous mixture with air, and in the second method so far as mantles are concerned, the cardinal principle is the flame temperature. In the second method (mantles excepted) and third method the cardinal principle is the total

heat evolved, and since far more gas is used in the second and third methods than in the first, it is now customary throughout the United States to read the value of a gas according to its total heating effect. The Public Service Commissions of the different states, whose duty it is to test the quality of the gas distributed by gas companies, have generally decided that the test of the quality of the gas shall be its total heating value, and this test is made with an instrument designed to show this value, which instrument is called a calorimeter. A description of the calorimeter will be found to follow that of the photometer in the appendix.

Fig. 25

Illuminating Gas, after Mixture with Oxygen, being used for Welding Purposes

In some places, as in Philadelphia, for reasons to be shown in the next chapter, the value of the gas is still determined by its light-giving qualities when burned through a lava tip without previous mixture with air; but in the remainder of the State of Pennsylvania, as in most other states, the Public Service Commission has decided that the heating value rather than the photometric value of the gas shall decide its quality.

It is important to observe that there is no fixed relation between the heating value of a gas and its light-giving value when burned in a lava tip. For instance, a sixteen-candle-power coal gas would have a heating value of 600 B.t.u. per cubic foot, while a two- or three-candle-power natural gas would have a heating value of nearly 1,000 B.t.u. per cubic foot.

The advantage of all these methods of using gas is, therefore, that the energy of the fuels and oils supplied at the gas works is stored up in the gas and distributed to the consumer for his use in as large or small quantities as he desires, and in this form permits of the application of the heat so as to get useful work from a greater percentage of that heat, and at less cost, than can be obtained in any other way. From the standpoint of conserving resources, it is interesting to know that about seventy per cent. of the energy in the coal can be delivered to the consumer's meter by gas.

The number of uses to which gas is adapted cannot be enumerated here and we must be satisfied with the statement that there are over one thousand uses to which gas is applied in the streets, offices, homes, factories, laboratories and the sciences and arts generally in Philadelphia. The following list enumerates a few as showing the wide diversity of its uses:

- Brazing
- Case hardening
- Caldron furnaces for:
  - Rendering lard
  - Boiling syrups
  - Melting wax
  - Making soaps
- China kilns
- Coffee roasting
- Candy making
- Forge
- Glue heaters
- Gas engine
- Heating machines for:
  - Ball bearings
  - Nuts, bolts
  - Needles, small blades, etc.
  - Tempering writing pens, links, buttons, etc.
- Japanning ovens
- Pressing irons
- Smokehouses
- Steam boilers (gas heated)
- Tire heaters

SERVICES OF THE GAS COMPANY:

After the gas of proper quality and quantity has been supplied to the consumers' premises by the company's mains, a very important branch of the company's work still remains.

The gas company's work is not done until the people of the city have had an opportunity to get all the benefits that may be obtained by them through the use of gas, and they must obtain these results through the exertions of the gas company, with the least possible trouble to themselves

COMPLAINT MEN:

There are representatives of the company on hand at well-known places ready to receive any notification from the public of any cause for complaint in the use of gas. The telephone directories show just how these people can be reached without delay. These men report the location of the trouble and its nature to the proper department, which proceeds at all hours of the day or night to apply the remedy. The gas company welcome these complaints eagerly as providing a means by which a further knowledge of all phases of their business can be obtained, and through which more satisfactory results can be obtained by the use of gas.

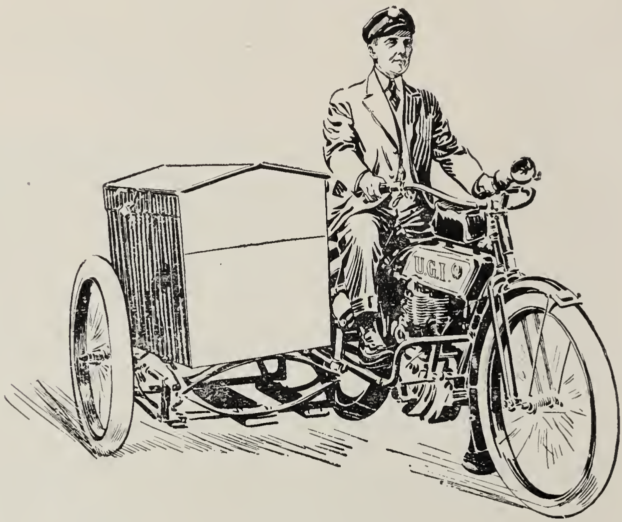
For replacing broken glassware in lamps and for adjusting and repairing appliances, a force of "Quick Service" men is maintained, and a familiar sight in the streets of our city is one of the "Quick Service" men hurrying to respond to a call.

NEW BUSINESS:

Representatives of the company should cultivate the confidence of the citizens to know, in all cases, if the use of gas appliances prove satisfactory. They are able to remedy faults in operation and see that the appliances give continual satisfaction to the consumer.

The gas company is also quick and keen to make the citizens acquainted with other uses of gas that would conduce to their comfort and convenience and is ready to show all modern appliances and explain their uses. This is done at frequent intervals.

Fig. 26



Quick-Service Man

To do this it is necessary that the gas company should carry on large experimental laboratories for testing new appliances to make sure before recommending them to their consumers that the appliances can be depended upon to do their work economically and safely, and that they are well made and economical also in space and first cost. The gas company must see that the apparatus is so placed and so connected with sufficient pipe as to do its work in the locality selected.

In the distribution of gas there must be constant study to see that new pipe of sufficient size is laid to reach the consumers in newly built-up districts as soon as the density of population warrants the laying of pipe; that the flow of gas through the mains, even in the older and more densely populated sections of the city, is studied constantly to determine where changes in piping shall be made to give good supply. The gas company also undertakes to give constant service to the consumers' lighting, keeping all fixtures and mantles in good condition and visiting them at regular intervals to see that they are so maintained. There must be attractive offices provided in locations easily reached for the payment of bills, for discussion of service obtained in the use of gas and for inspection of new appliances for light, heat and power. There must also be provided shops and storage yards for pipes, meters and other apparatus to reach quickly any portion of the district supplied by the company. There must be shops for the testing and repairing of meters to be sent out and set on short notice.

The result of all this is that the citizen is so accustomed, when turning on a cock or valve, to have instantly a flow of gas through his burner or appliance best adapted to his need, that little thought is given by the community at large to the plant and system that is required to furnish this uninterrupted supply of light, heat and power. In the works a large expense is incurred in providing extra apparatus which may be put in operation at short notice to take care of unusual demands. Enough gas to last for hours is already made and stored in the holders ready to flow out through the mains to the consumer. Large quantities of raw materials for gas making are provided and stored in the gas works to insure operation in times of strikes on railroads, in the mines, or congestion on the railroads, or other causes beyond the control of gas companies.

The gas companies have thus impressed on the minds of the citizens a reputation of always having their commodity ready for use, independent of disturbed business conditions, storms, floods and other phenomena that so seriously interfere with public utilities in general and from which the gas companies are secure because of the great network of pipes which are laid under the ground and go thence directly into the houses of the consumers.

It was said of the ancient Egyptians that they never discussed the state of the weather because one day was exactly like another. It is the desire of the gas companies to enjoy a reputation of this kind by having their supply continuous through years of service and always the same in quality.

In cities today gas is the principal agent employed for cooking. Above are shown types of gas ranges such as are found in practically all city homes

Philadelphia Gas Works

Gas manufacture and distribution was first started in Philadelphia in 1836 and has been in continuous operation for the ensuing eighty-one years. On February 10, 1836, forty-six public lamps on Schuylkill Second Street (now Twenty-first Street) and nineteen private burners in the only two dwellings that were prepared for the introduction of gas, were lighted for the first time.

The business of gas manufacture and sale in this city has always been owned by the city itself. In this it is unlike any other large city in this country and has brought about one peculiar result,—there has never been any competition in Philadelphia in the sale of gas nor more than one system of mains in the streets. The City of Philadelphia has never granted a franchise or allowed any other company to sell gas herein; whereas, in other cities a number of competitive companies have been granted franchises from time to time, and without exception they have later joined together into one large company controlling the sale of gas for the whole city.

A few items of the history of the Philadelphia Gas Works are to be noted. In the early years of gas lighting, the boundaries of the city were the two rivers and South Street and Vine Street. The communities lying without these boundaries were not supplied with gas from the city works and they, therefore, had to build works of their own, and in this way gas works were started in Frankford, Manayunk, Germantown, Moyamensing, Bridesburg, Spring Garden, Northern Liberties, Kensington, and because of its remoteness, a special municipal plant for the House of Correction. As Philadelphia expanded its boundaries, these smaller communities were incorporated into the City, and the pipes of the Philadelphia Gas Works were extended to connect with the pipes of these smaller communities. Each of these smaller companies in turn was incorporated into the city gas works, with the exception of the Northern Liberties and the small municipal plant at the House of Correction in Holmesburg which supplies a small number of houses in the immediate vicinity. The Northern Liberties Gas Company still continues to sell gas in its district. The City of Philadelphia owns a portion of the stock of this company and there is no attempt on the part of the city gas works to invade the Northern Liberties district, nor can the Northern Liberties Gas Company go beyond its boundaries into other city streets.

The result of the final closing of these smaller outlying plants has been to release their sites, formerly occupied by them as works and holder stations, for the erection of large outlying gas holders to which gas is pumped at high pressure from the works through large pumping mains, independent of the distribution mains. The use of these holders in the locations so fixed many years ago is important because it permits an enlargement of the small systems of distribution mains so that gas can be furnished to the entire city with smaller changes in pressure than would

have been possible if all of the gas had been sent out direct from the holders at the works. If this latter course had been adopted during the eighty-one years, it would have been necessary to have enlarged the entire system of mains several separate times at enormous expense. These outlying holders are now located at:

Mifflin Street between Eighth and Ninth Streets.

Market Street between Twenty-second and Twenty-third Streets.

Chestnut Street between Forty-seventh and Forty-eighth Streets. (Figure 27.)

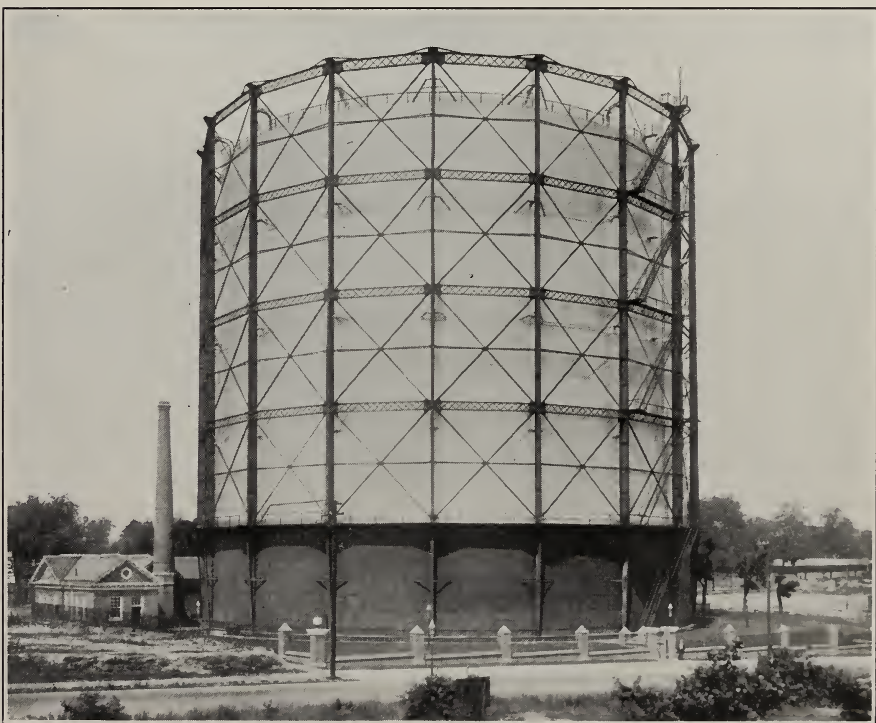
Ninth Street between Norris and Diamond Streets.

G and Venango Streets.

Belfield Avenue and Collom Street, Germantown.

Shurs Lane and Main Street, Manayunk.

Fig. 27



Gas Holder Station

The first gas works was located on both sides of Market Street along the Schuylkill River. In 1850 the necessity for additional gas supply was clearly shown and it was decided to build a new gas works at Passyunk Avenue and Schuylkill River. This works was started on December 13,

1854, and large mains were laid in the ground to connect these works with the system of mains radiating from the works on Market Street.

In 1875 the demand for additional gas in the northern section of the city was met by the building and starting up of the gas works located at Tioga Street and the Delaware River.

In 1897 it became evident to the Select and Common Councils of the City that the operation of the gas works was not being conducted economically, nor was the money being appropriated by them out of the general funds of the city sufficient in quantity to enlarge the works and distributing mains so as to keep pace with the additional demands for gas due to growth of the city. The gas works was considered a very valuable asset which Councils were reluctant to dispose of by sale and, accordingly, it was decided to lease the gas works to The United Gas Improvement Company, which organization was known to be experienced in the operation of gas works by reason of owning and operating works in other cities.

Under the agreement of the lease the lessees were required to provide all the gas used by the city for illumination in its offices, fire houses, schools, etc., free of charge; to supply the gas free of charge and to light, extinguish and maintain in good order all of the street lamps in use at the time of the lease and to erect 300 additional lamps each year; to expend at least $15,000,000 in improvements, extensions and betterments to the plant during the thirty years' duration of the lease; to furnish a good gas of at least twenty-two candle-power, as measured at a testing station located not less than one mile from the works; to collect all the money due from the sale of gas to private consumers, and to pay into the City Treasury all the money received over ninety cents per thousand cubic feet of gas sold during the first ten years, over eighty-five cents for the next five years, over eighty cents for the next five years, and over seventy-five cents for the last ten years.

The Councils of the City retained the right to fix the price of gas, which it was agreed should not be over one dollar per thousand cubic feet. In this way the City Councils could choose between making the rate for the sale of gas equal to the amount that the company was to receive, thereby reducing the gross revenue of the City approximately $2,000,000 per year over what they would receive if the rate were maintained at one dollar per thousand cubic feet.

Another article of agreement in this lease was that the original gas works site at Market Street and the Schuylkill River should be abandoned as a gas manufacturing station. This was accomplished in 1898, and there are at present two manufacturing stations, one at Passyunk Avenue and the Schuylkill River—known as Station "A," and one at Tioga Street and the Delaware River—known as Station "B." At each of these stations both coal and water gas are made and the gases mixed so as to insure a twenty-two candle-power gas delivered at the respective testing stations. The City of Philadelphia has, therefore, adhered to rating the value of its gas according to the candle power, while most of the other cities in this country now rate their gas according to its heating value. At the time the lease was executed between the City of Philadelphia and the company operating the gas works, no company in the country rated its gas according to its heating value. The candle power of the gas is measured daily by the City's Gas Inspector who also, upon complaint of any consumer, will test

his meter, the company maintaining two gas-testing stations and a meter-proving station for the use of the city officials.

In the previous chapters we have described and illustrated the chemical and mechanical processes used in gas manufacture. We have there shown the generation of gas, its cleaning and purification as a continuous process. In a gas works the size of those required to supply Philadelphia, each of these processes occupies separate and detached buildings. Each of these processes requires several large buildings in each works and the care and detail necessary to obtain a high degree of efficiency could not be dwelt on in detail in a pamphlet of this kind.

The consumption of gas in Philadelphia on a cold winter day in 1917 would have been sufficient to have furnished one Welsbach burner, such as is used in house lighting, with gas for continuous burning throughout the twenty-four hours of the day for about 1,725 years.

At the gas-manufacturing stations there must be carried in stock at all times millions of gallons of oil, and the stocks of coal approach 100,000 tons.

The gas stored in the holders at sunset is generally sufficient to last throughout the night until the following morning.

The system of distributing mains of the Philadelphia Gas Works now consists of 1,551 miles, of which 1,409 miles are over three-inch. These mains, if placed in one straight line, would reach from Philadelphia to Vicksburg on the Mississippi River. The large mains are called "trunk mains;" of these a main thirty inches in diameter extends from Richmond and Tioga Streets to Front and Market Streets, a length of 4.2 miles. Another thirty-inch main extends from Station "A," at Passyunk Avenue and the Schuylkill River, in Passyunk Avenue to Sixteenth Street, up Sixteenth Street to Lehigh Avenue and west to Twenty-second Street, a distance of 6.5 miles. From the holder station at G and Venango Streets a 48-inch main extends under the Pennsylvania Railroad north to Erie Avenue, a distance of 1,800 feet. There are forty-five miles of twenty-inch mains in the distribution system and from these large mains connections are made to carry the gas along each street of the City, the mains being connected in such a way as to support each other in maintaining an adequate flow of gas without great changes in pressure. In addition to these mains another system, leaving each works, thirty inches in diameter and reducing finally at the outlying stations to sixteen inches in diameter, has been laid so that gas can be pumped from either of the manufacturing stations to any one of the outlying holder stations, or from one works into the holders of the other works, without in any way interfering with the pressures in the gas-distribution mains. These holder stations must discharge their gas into the distributing mains without undue loss of pressure, and it is therefore clear that, unless a holder station is to be accompanied with the heavy expense of providing very large diameter mains connecting with the distribution system, that the location of these new holder stations shall be determined by the condition, size and pressure in the gas mains then existing in the streets.

METERS:

No business is so intimately associated with the entire body of citizens as that of supplying gas, except the still more important business of sup-

plying water. In this City there were, according to the Chamber of Commerce report of December 31, 1916, 370,000 residences; to supply these as well as stores, factories, offices, etc., there were in place at the same date 399,356 gas meters, not including those placed by the Northern Liberties Company and the municipal plant at Holmesburg. The business of keeping the records and accounts of this number of consumers is one that requires application of the most efficient methods in order that all consumers shall be treated fairly; that no opportunity shall be lost for instructing and encouraging them in the advantages and comforts to be obtained from the use of gas by reason of new applications and inventions, and that the records of none of the consumers be lost, notwithstanding the great proportion of the citizens who move from one premises to another throughout the year. If one could inspect these records he would be led to believe that the nomadic character of our citizens is strongly established. New houses are being erected at an average of about 7,000 each year and each of these houses must be connected to the gas mains with service and meter. Frequently, mains must be laid in streets where none was laid before, and this should be done before the final paving. The work of the Distribution Department, therefore, is not confined to any one portion of the City but exists in every street and avenue. Their stockyards, storehouses and workshops must be located in each district; their working gangs will be found here and there continually throughout the City (Figure 28):

Fig. 28

Laying Large Gas Mains in City Streets

The distribution shops and yards are located as follows:

1931 South Ninth Street.
1615 North Ninth Street.
4650 Market Street.
20 West Maplewood Avenue, Germantown.
4427 Frankford Avenue.

In the City the gas meters are taken out at regular intervals and tested. This requires that there shall be on hand a great number of extra meters, and a large force of men employed continuously in this periodic testing of them. Such meter-testing stations are located at:

1931 South Ninth Street.
1615 North Ninth Street.
4650 Market Street.
20 West Maplewood Avenue, Germantown.
4427 Frankford Avenue.
19th Street and Allegheny Avenue.

Offices are open in the districts for the collection of bills, for receiving orders for the setting of meters to supply gas to new consumers, for receiving notices of removal of consumers from their premises, and for such complaints as occur from various causes from time to time. Such offices are located at:

Main Office	Broad and Arch Streets.
Down Town	Broad and Tasker Streets.
Spring Garden	1706 North Broad Street.
West Philadelphia	135–137 South 52d Street.
Frankford	4417–21 Frankford Avenue.
Kensington	2209–11 North Front Street.
Germantown	5534 Germantown Avenue.
Manayunk	4236 Main Street.
Bridesburg	2661 Bridge Street.

At each of these offices there is an exhibit of gas fixtures, appliances and lamps in great variety. Competent employees are in charge to explain the uses and adaptability of the appliances and to arrange for their installation.

These stores come under the supervision of the New Business Department. This department is responsible also for the men who visit the consumers at their homes to sell gas appliances and lamps; for the Burner Maintenance Division which cares for lamps that have been installed on maintenance contracts and for the Instruction Division which consists of women who visit the housewives to show how they can get the best results from the appliances they have bought.

Finally, the Advertising Department keeps constantly before the public the advantages to be derived from the use of gas, and this is done by persistent and continuous advertising in the daily papers, by small pamphlets bearing on the subject, by window displays and special exhibits in connection with national, state and city exhibitions, and exhibits devoted exclusively to gas appliances.

Appendix

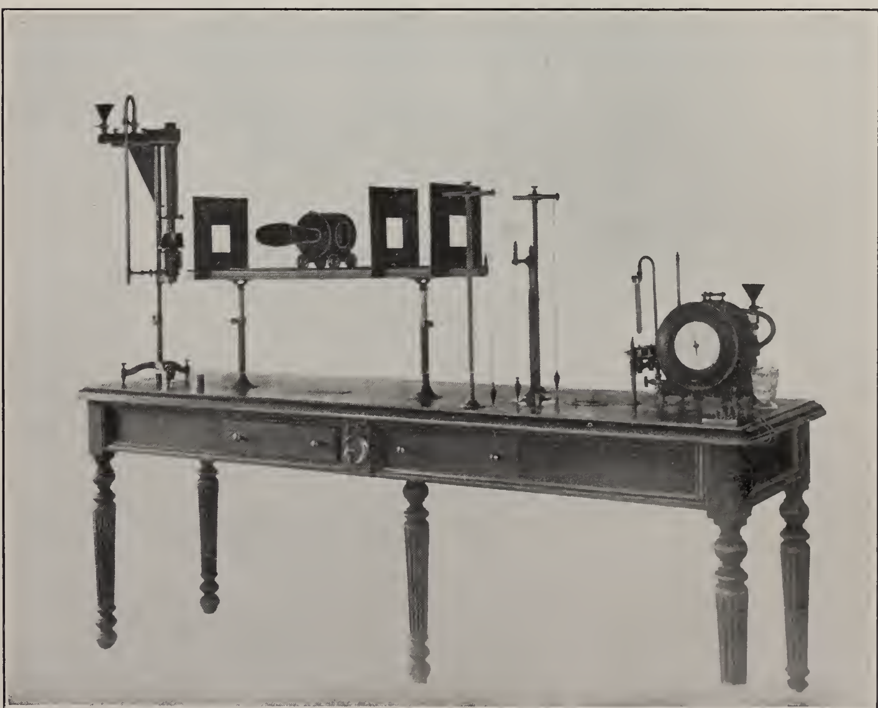
Photometer

The intensity of light from a gas flame is measured in a horizontal direction on an instrument called a "photometer" and is expressed in terms of the number of standard candles that would be required to be consumed to give the same intensity of light when measured in a horizontal direction.

The standard candle is the unit for measurement of all luminous flames. It is a sperm candle made according to specifications set forth by an Act of Parliament in Great Britain in 1871, which describes in complete detail how all parts of the candle shall be prepared and assembled and the care to be observed in its burning. This standard candle is the only unit of light that has so far received the official sanction of any central government and it has been in use in photometrical work for forty-five years. It is not now, however, as much used as formerly because of the length of time required to make a test with candles and the difficulty of keeping the candles in proper condition in warm climates, and to the fact also that the source of supply is solely in London.

Figure 29 shows a photometer mounted on a table.

Fig. 29

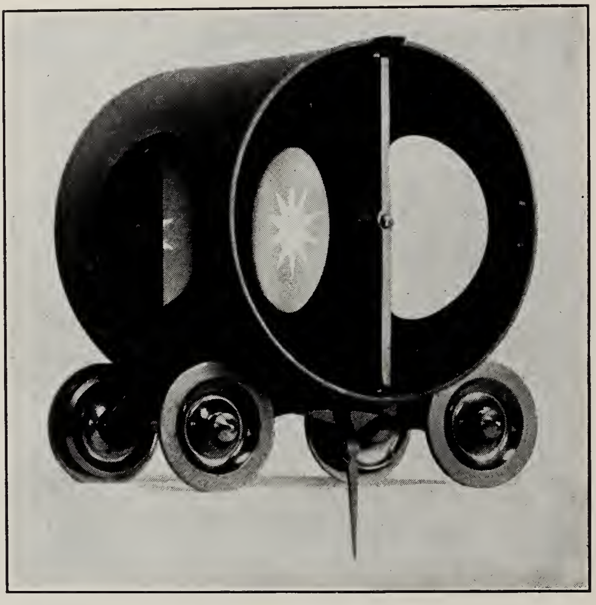


Gas Photometer

Accordingly, Sir Vernon Harcourt invented what is known as the Ten Candle Harcourt Pentane Lamp which, burning a very carefully prepared hydrocarbon oil called pentane, can be made to give a luminous surface of steady uniform value of approximately ten candles. This lamp has been in use for some years, has undergone extensive tests and has now received the approval of the United States Bureau of Standards at Washington, and the committee of the House of Parliament in England.

The photometer consists of a graduated bar sixty or one hundred inches long, to the right of which is shown the burner from which is emitted the flame to be tested, and at an equal distance from the center of the bar, at the left end, a ten-candle pentane lamp. The plumb-bobs are used to check the distances from the center of the bar. On the table on the burner side is located a meter through which the gas, in passing to the burner, is carefully measured, a thermometer being inserted in the meter for determining the temperature of the gas; and a small gas governor for securing uniform pressure throughout the test.

Fig. 30

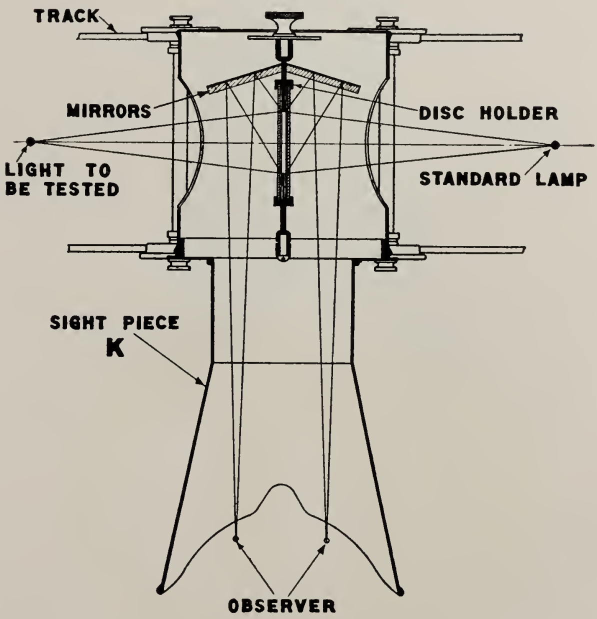


Disc Box

Rolling on a small double track, to which is fastened a graduated bar, is the disc box (Figures 30 and 31). It consists of three pieces of white paper. The middle piece is of thicker paper, uniform in quality and finish on both sides, and has a star stamped from its center. On each side of this is placed a thin sheet of white rice tissue paper. These three pieces are cut round and pressed between two discs of white French plate glass, so that their surfaces are flattened out. The star portion of the disc, being thinner, is more translucent than the surrounding field, and when held up to the light appears brighter. At the back of the disc holder and fixed at an angle of

sixty degrees with the plane of the holder are two small mirrors, one on each side, so that when the disc holder is placed in the disc box and the sight piece "K" is fastened to the front of the disc box, an observer looking through can see the reflected light from the disc in the mirror on each side. The disc box being in place, if one of the lights is screened, the observer upon looking at the mirror on the side towards the unscreened light will

Fig. 31



Details of Disc Box and Sight Piece

see a bright reflection from the disc paper, except at the point of the star where the translucent paper will permit certain of the rays to go through and consequently will show the star as darker than the surrounding paper. If now, both lights being lit, the disc is placed at that point in the bar nearer the weaker light, where the amount of light from each side falling on the disc is the same, the amount of light that passes through the translucent paper on one side will be equal to the amount of light passing through the translucent paper from the other side and the reflection from the star will be equal to the reflection from the paper and the star will appear equally bright in both mirrors. The pointer at the bottom of the box will now show the relative distance that the disc is from each light and, therefore, the number of times that the gas flame is brighter than the flame of the pentane lamp can be calculated by the rule that the intensity of light from each source is inversely proportional to the square of the distance. That is to say, if the disc is found to be thirty-six inches equals three feet from the gas flame and twenty-four inches equals two feet from the pentane lamp when equal illumination is observed on both sides of the disc, the intensity of the

Fig. 32

Sight Piece "K"

gas flame will be $\left(\frac{3^2}{2^2} = \frac{9}{4} = 2.25\right)$ two and a quarter times that of the ten-candle pentane lamp, or the gas will be 22.5 candle power.

The candle power of the gas at the observed rate of consumption must be corrected in proportion to what it would have been if the consumption had been shown to be at the rate of five cubic feet per hour on the meter; and there must also be a correction for the atmospheric pressure and standard, which is taken at thirty inches mercury by the barometer.

Calorimeter

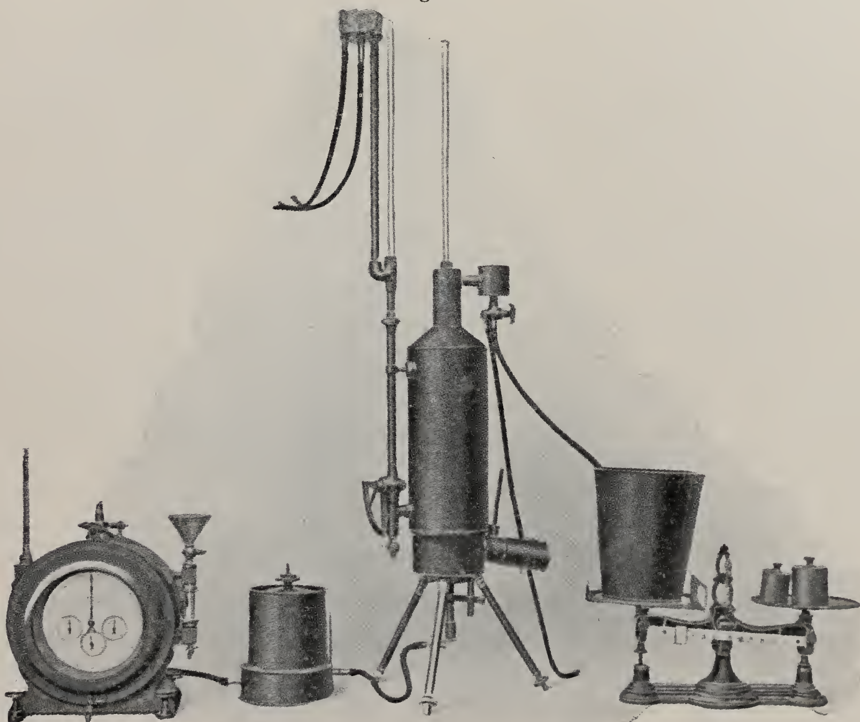
The heating value of a gas is defined by the total heating effect produced by the complete combustion of the gas with air of the same temperature, the products of combustion being brought to the initial temperature of the gas and air.

The heating effect is stated in terms of British thermal units.

The British thermal unit is the amount of heat required to raise one pound of water one degree Fahrenheit from its temperature of greatest density 39.1°.

Figure 33 shows a calorimeter complete with its auxiliaries for determining the heating value of illuminating gas.

Fig. 33



Junker's Type Calorimeter

The gas first enters the meter at the left, which is of wet experimental type, having water as the lower confining surface in its measuring compartment. The level of this water may be raised or lowered, as indicated on the water gauge at the side. A drum having four chambers revolves on a horizontal axis centrally located from front to back of the meter, the front end of this axis projecting through the meter case and bearing a hand. This hand travels, therefore, directly with the drum's rotation, and indicates

on the dial fractional revolutions, while other hands geared to it register complete revolutions (each one-tenth of a cubic foot) and multiples by ten thereof.

The four drum compartments are separated by partitions warped like the surface of an Archimedes screw, the water level being at such a height that the upper chambers are filled with gas and the lower with water. With Archimedes (using water), power was applied to revolve the screw and caused the water to flow through. With the wet meter, conversely, using water below and gas above the gas flows through under pressure, supplying the needed power, and the screw (or drum) is made to revolve. Advantage is taken of this revolution to register volume passing. The meter is provided with a thermometer to indicate the temperature of the gas during measuring, while the barometric pressure is determined at the same time in order that the gas passing as indicated by the meter may have its volume corrected to standard conditions, namely, thirty inches barometer and sixty degrees Fahrenheit.

The gas next passes to the small cylindrical instrument shown. This is a wet governor with a gas bell over water built upon the general idea of the works governor before described. On its top, weights are placed to maintain the pressure of the gas, leaving it exactly uniform as indicated by its U-gauge so that the transfer of heat from the gas to the water flowing through the calorimeter will be at a steady, uniform rate.

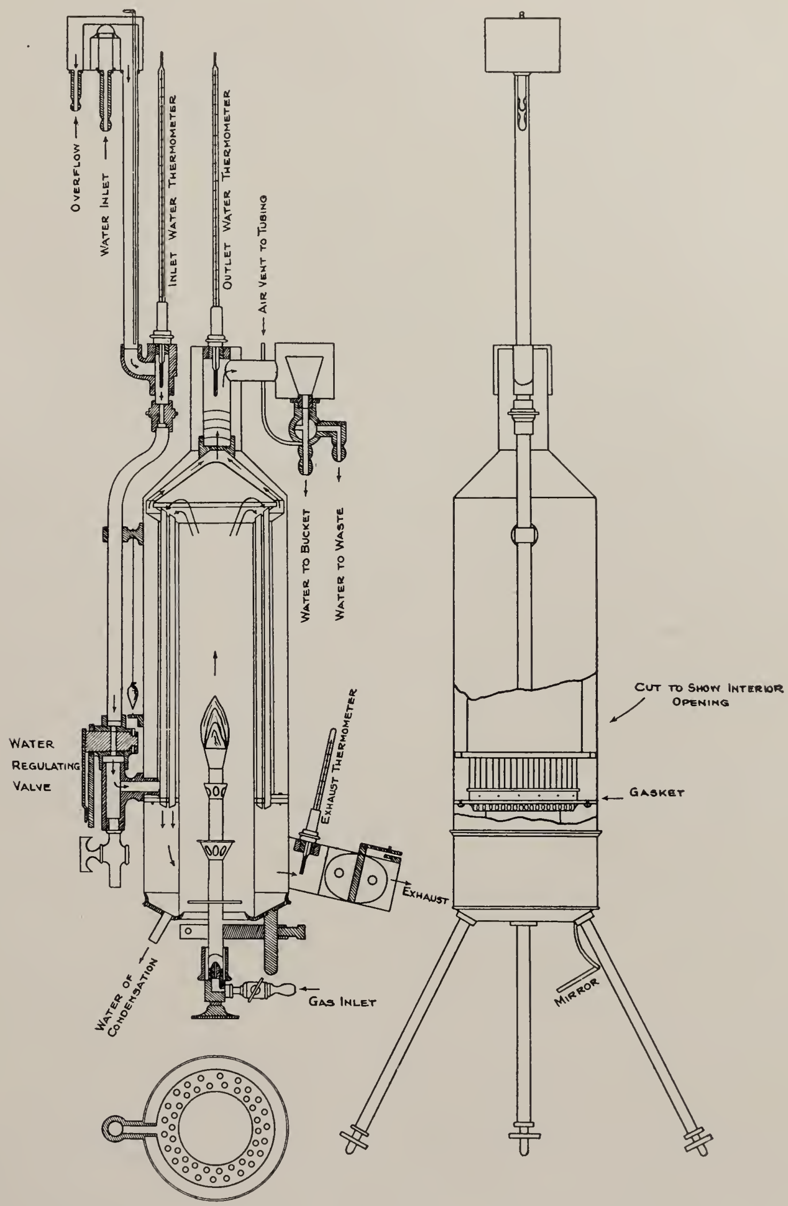
The gas next passes to the Bunsen burner inserted beneath the calorimeter proper, this burner having a cock by which the rate of gas flow can be controlled between the limits fixed for most efficient performance of the calorimeter, usually with illuminating gas from five to seven feet per hour.

This Bunsen burner has a cap which causes the flame to spread at its top, so as to play closer to the combustion walls. The Bunsen tube is held vertical with its axis coinciding with that of the cylindrical combustion chamber, as shown in Figure 34, by means of a clamp arm sliding on a flattened rod, against which it is set by a screw. After the gas is lighted and adjusted with primary air until all luminous flame just ceases, the Bunsen is inserted until the flame is five or six inches up the chamber. A small mirror placed at an angle near the bottom shows whether the flame continues to burn properly and to permit further adjustment of the primary air if necessary.

The products of combustion rise inside the combustion cylinder (Figure 34) until they strike the inner hood and then pass down through the tubes to the lower annular compartment and out through the outlet flue to the air. In the passage up the inside of the cylinder and through the tubes they impart their heat to the surrounding walls and emerge from the apparatus at a temperature either exactly or very nearly that of the entering water, which should be the same as that of the air. This may, in part, be controlled by the damper shown, the exhaust thermometer indicating correctness of the temperature. As water is formed by the combustion of the hydrogen in the gas it is condensed during this cooling and runs off through the small pipe tapped into the ring closing the bottom of the lower annular compartment, dropping into a small measuring glass, for purpose of record.

The calorimeter proper is best understood through a reference to the

Fig. 34



Details of Junker's Type Calorimeter

sectional view given in Figure 34, paying particular attention to the arrows indicating the direction of gas and water flow. Its outer diameter is about seven inches, its diameter inside the combustion chamber is four inches. The body of the instrument over all is about twenty-eight inches, and the total height, from bottom of legs to top of inlet water cup, fifty-six inches.

It is constructed of copper sheets with fittings of brass. Its entire outer surface is nickeled and highly polished to prevent heat loss by radiation. The legs, water connections and circular nest of condensing tubes are removable for repair or examination. The tripod legs are adjustable in length to secure verticality, using plumb-bob shown above water regulating valve.

The outer polished casing of the calorimeter body has a clearance of about one-half inch from the outer casing of the ring nest of condenser tubes, and this annular clearance space (see horizontal section below in Figure 34) is filled with air for heat insulation.

The flow of water through the calorimeter is regulated by a valve with a hand moving over a graduated arc. Usually, the flow is so adjusted as to secure a fifteen-degree F. rise in temperature of the outlet over the inlet thermometers. Below this valve is a "T" head cock through which all water is drawn from the calorimeter when it is to be put out of use.

Below the bulb of the outlet thermometer is shown a series of curved lines. These represent sections of bafflers, in the shape of convex discs with a horizontal slot cut part way across each. By arranging these slots at angles with each other any direct currents are broken, and thus the temperature of the flow as a whole is quite uniform while being registered at the outlet water thermometer.

Since the temperature of the atmosphere in the room and of the inflowing water are kept as nearly alike as possible, there will be no rise in the temperature of the inlet water after measurement due to the air in the room.

The outlet or hot-water funnel is provided with a two-way cock by which during the process of measuring the weight of water heated, this hot water may be instantly diverted from the "waste" to the "bucket" or *vice versa*.

On the right of Figure 33 is shown the weighing device used with the calorimeter. It consists of a balance, on one platform of which is placed the copper bucket to catch the heated water, and on the other are placed the pound weights to counterbalance or weigh it. The exact balance is obtained by a sliding counterweight which registers to one-hundredth of a pound.

When it is desired to make a determination of the calorific value of a gas, the apparatus is set up on a firm base in such a position that it can be readily supplied with the gas to be tested and with flowing water. The thermometers provided for the purpose, which are graduated in tenths of degrees Fahrenheit from usual room temperatures (about 60°) to 110°, should be inserted in the proper openings, as shown in Figure 34. Connection is then made with the water supply by means of rubber tubing slipped over the nipple of the water inlet. A rubber tube leading to a drain is slipped over the nipple marked "overflow," another tube is slipped on the nipple leading from the hot-water funnel to water "waste," while a fourth tube is supplied to lead from hot-water funnel to bucket. Water being turned on flows to the inlet cup and thence down past the bulb of the inlet

water thermometer, through the water-regulating valve and into the annular space at the bottom of the tubes. It rises around the annular nest of tubes, absorbing heat from their outer surfaces, through the conical passage and into the central riser, in which it is thoroughly mixed by the baffle rings, then around the bulb of the outlet water thermometer inserted into the top of the riser and thence by the side pipe to the cup in which it rises until it overflows into the funnel and passes away through the two-way cock. Water should be admitted into the outlet cup at a faster rate than that at which it is passed through the water-regulating valve so that this cup continually overflows into the larger cup and to the drain. In this way a constant head for the supply of water is maintained, and as the water also overflows into the funnel on the outlet at a constant height, the effective head is constant and the water must flow through at a constant speed as long as the water-regulating valve remains set at any given opening.

The heating value of the gas is obtained by passing a given volume, say one cubic foot of it (corrected to 60° F. and 30 inches barometer) through the meter, and collecting the amount of water heated during the exact time the gas was being metered. This water is weighed in pounds, its rise in temperature noted in degrees Fahrenheit, and the product of these two quantities will give the number of British thermal units contained in the one cubic foot of gas.

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